JPRS L/10095

4 November 1981

Translation

MICROPROCESSORS

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JPRS L/10095

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Moscow MIKROPROTSESSORY in Russian 1981 (signed to press 24 Mar 81) pp 1-70

[Text of brochure "Microprocessors" by Mikhail Alekseyevich Bedrekovskiy, Nikolay Serafimovich Kruchinkin and Vladimir Andreyevich Podolyan, Izdatel'stvo "Radio i svyaz'", 60,000 copies, 71 pages]

CONTENTS

Annotation

Based on a systematic discussion of data reflecting the key properties of and experience gained in using domestic and foreign microprocessors, a demonstration is given of their capabilities and design structure, as well as of aspects of their use in specific equipment.

For a wide range of readers.

Foreword

The attention of specialists in various fields of technology has been attracted more and more by promising microelectronic products--large-scale integrated circuits with program-controlled digital data processing functions.

Of course, any information problem can be solved in principle by breaking it down into individual data processing functions and by performing these functions in a specific order specified by a program. A fundamentally universal integrated microcircuitry element which implements a solution process specified by a program is the microprocessor, which has appeared as the result of the evolutionary development of microelectronic technology and of the aspiration of making possible by means of this technology maximum completeness of the functional properties of computer hardware elements.

The introduction of microprocessors into various kinds of industrial, household and even amateur radio equipment can undoubtedly be furthered by a description of their capabilities, advantages and know-how gained in using them in a publication intended for a broad reading audience. In the extensive existing literature on microprocessors these questions are discussed on a professional level, which as a rule exceeds the comprehension abilities of nonspecialists.

The purpose of this brochure is to attract to microprocessors the attention of the popular reader whose field of specialization or interests involve in one way or another the use or development of electronic equipment for a broad range of applications--from computers to electronic home appliances. The key elements of the structure of microprocessors are discussed in this brochure. A description is given of the organization of storage devices, the operating principles of microprocessor systems and properties of them, such as the bus line principle, the possibility of interrupts, and direct access to the memory, as well as the essence of microprogram control, programming languages, etc.

The system of technical parameters and the key characteristics of the most widely used types of domestic and foreign microprocessors are presented. An analysis is given of aspects of their application and examples are given of the specific implementation of equipment based on them.

The aspiration of maximum simplification and of a popular mode of presentation, in a number of instances to the detriment of depth and rigor, can probably be justified by the above-stated goal.

It is requested that comments regarding this book be sent to the following address: 101000, Moscow, General Post Office, Box 693, Izdatel'stvo "Radio i svyaz'", Popular Radio Library Editorial Board.

Introduction

To the questionnaire question "What is your personal opinion on a microprocessor?" presented by the American journal INSTRUMENTATION TECHNOLOGY to its readers--users and developers of industrial automation equipment--the answers were distributed in the following manner: 53 percent answered "Incredible, fantastic!", 27 percent "Microprocessors will find application as control elements" and 20 percent "Opinion not definitely formed, but it will be difficult to work with them the first time" [1].

A brief analysis of these responses makes it possible to draw one conclusion which is important and interesting to us. The first group of responses is just as emotional and unspecific as the second and third are reserved and businesslike. The lack of unanimity in this question becomes understandable if allowance is made for the fact that to the questionnaire question "Where do you use microprocessors at the present time?" half of the readers responded "Nowhere!" it is quite likely that it is precisely this half which made the enthusiastic comment.

It will obviously be proper to assume that the effective application of microprocessors (MP's) in reality is more complex than is assumed before the acquisition of experience in working with them and the reason is primarily the lack of this experience. At the same time the idea of implementing a programmable digital device with the properties of a computer processor using a minimum number of large-scale integrated circuits (LSIC's), on which microprocessors are based, is indisputably highly promising.

In giving an evaluation of the state of the art of the development and introduction of microprocessors, as well as of the prospects of the immediate future, abroad they not infrequently speak of the "second computer revolution," "the explosion in data processing technology," "the microcomputer invasion," and the like, stressing the explosive nature and great significance of the penetration of microprocessors into all areas of life.

According to forecasts of the West German firm Siemens AG, the number of large-scale integrated circuits with programmable operating logic produced in Western Europe in 1980 will equal 20 percent and in 1985 about 40 percent of the total annual output of integrated circuits (IC's) [2]. In the USA sales of microprocessor chips alone have doubled every two years, and saturation of their market is not foreseen at least in the foreseeable future, since the need and ability of microprocessors to master new areas of application are growing still more rapidly.

What are the reasons for this such swift invasion of microprocessors into everday life? The main reason resides in a microprocessor's uniting the universal capabilities of a programmable computing facility with the advantages of large-scale integrated circuit technology--relatively low cost, high reliability and economy. The consequence of this is the remarkable ability to create both exceptionally "flexible" microprocessor LSIC's (MP LSIC's) aimed at solving a very wide range of problems with greater or less effectiveness and narrowly specialized MP LSIC's which most effectively solve one or more problems specific to certain applications.

Able to be offered as an example is the LSIC of the domestic series K587 microprocessor--an arithmetic unit (AU) performing the functions of a universal processor, and an arithmetic expander (AR)--a processor oriented toward fast multiplication and several other operations.

Thus, the specialization of MP LSIC's or, on the other hand, their universality must be considered primarily in determining their effective area of application. Here it must be kept in mind that a large group of problems can be solved most effectively by uniting the functions of a universal microprocessor and special-purpose MP LSIC's, by distributing parts of the general solution algorithm among individual special-purpose MP LSIC's and processing their results by means of a universal MP. This idea forms the basis of a number of the best domestic and foreign microprocessor sets (MPK's) in which the structure of the LSIC's, in addition to data-logic electrical and design compatibility, to one extent or another also satisfies the requirement of functional completeness, the degree of which obviously also determines the universality of the application of an MPK.

Dialectical unity of the general and particular, of the universal and special, realized in a number of MPK's has served as a scientific basis for creating the ideology of the domestic Unified System of Microprocessor Sets (YeS MPK)--a unified series of MPK's distinguished by speed and their fabrication technology [3].

The functional completeness of sets is made possible by a combination of 15 to 30 LSIC's having the structure of a universal or special processor and oriented toward the effective solution of various problems.

The number of types of MPK's produced abroad has recently exceeded 100, and there are many sets of approximately equal execution rate and functional structure, differing only formally, but incompatible in terms of key characteristics of the structure and software. In this connection precisely at the first stages of mastery special importance is taken on by the development of unified design principles for MPK's aimed at eliminating redundancy and an excessive increase in their nomenclature. It is gratifying to mention the well-timed approach to solving this problem by Soviet specialists and their leading role in the creation of a unified system making possible in addition to real universality the fulfillment of requirements for the unification of MPK's.

The general appearance of some YeS MPK LSIC's is shown in fig 1 [photograph not reproduced].

Meanwhile it is necessary to mention the existence of restrictions making it impossible or unfeasible to design and use systems based on MPK's in a number of cases.

Microprocessor systems lose to systems implemented with nonprogrammable ("hard") logic in the case when it is necessary to ensure high data processing speed (one million operations per second and more). It is also considered inadvisable to use MP LSIC's for designing systems of low complexity, i.e., those which can be designed by using a few dozen "hard" logic integrated circuits with a low degree of integration. In this case designing turns out to be simpler, takes less time and can be performed by traditional methods.

It must be mentioned that methods of designing systems based on MPK's differ radically from the traditional methods of logic design which are used by developers of systems employing integrated circuits.

At the disposal of the developer of a system employing integrated circuits are various logic elements, each of which performs, as a rule, one or a small but unchanged set of logic functions, such as AND, OR and NOT in various combinations, etc. Logic design in this case consists in finding the specific physical relationships between these elements as the result of the establishment of which a structure with the required logic functions is obtained.

In designing systems utilizing MP LSIC's this method cannot be used, since the developer has to deal with elements whose functions are of many types and are determined by the instruction set characteristic of each specific MP LSIC, i.e., are software determined. Therefore the problem of designing a microprocessor system reduces basically to programming its functional properties, and there can be a limited number of strictly physical structures based on a single set of MP LSIC's, and their development can be carried out by developers of MPK's simultaneously with the creation of MP LSIC's themselves. From this it follows that the effective design of microprocessor systems requires special training and special hardware furnished with special operating programs.

Only such an approach to designing makes it possible to realize the capabilities of MP LSIC's with respect to reducing the time required for and the cost of developing MP systems, to their "flexibility," i.e., their adaptability to a wide range of problems, and to optimization in terms of speed for a given problem, and in the development of complicated systems this approach is the only one possible.

The properties and characteristics of MP's are discussed below from the viewpoint of the ability to use an MP with maximum effectiveness in various MP systems. The terminology generally accepted in computing technology and microelectronics, applied to microprocessors almost completely without changes, is used. Additional concepts are as a rule defined in detail in the text. Presented below in alphabetical order [in Russian] are brief definitions of terms encountered in the text and compiled on the basis of analyzing and generalizing a great amount of published data.

Address--indication of the location of a storage location in a storage unit.

Accumulator, accumulator register--a register which stores the results of previous operations for the purpose of using them in subsequent operations.

Algorithm--a set of instructions uniquely determining the content and sequence of the performance of operations for solving a specific problem in the form of a step-by-step procedure.

Assembler, assembly program--a service routine which converts symbolic instructions in the assembly language into machine language instructions and which also performs certain auxiliary functions.

Large-scale integrated circuit (LSIC)--an integrated circuit containing from 100 to 10,000 logic elements.

Binary code--a code for the representation of data, written in the form of a series of 0's and 1's. The existence of many physical analogues (on/off, plus/minus, etc.) makes its use convenient in digital technology.

Display--a unit for converting binary information into a visual image and/or vice-versa (a digital display, a cathode ray tube display, graphic terminal).

Integrated circuit (IC)--an electronic circuit fabricated on the surface or in the body of a semiconductor chip and containing two or more components (transistors, resistors).

Interface--a combination of equipment for unified coupling between the component parts (subsystems) of a data processing system, including hardware and a protocol, i.e., a set of rules establishing unified principles for the interaction of subsystems.

Command, instruction--a single step in the operation of an operating unit, represented in the form of an instruction in machine language. The command determines the operation to be performed and its attributes.

Compiler--a service routine for converting an operating routine represented in a high-level language into a form at the machine language level while preserving the logical structure of the routine.

Cross software--a set of routines for creating and debugging the software of a computer different from that on which this software is prepared.

Logic element (gate)--an elementary circuit which implements a switching function and has two logical states.

Bus--a general-purpose line for the exchange of information between various elements of the structure of an MP or MP system and peripherals.

Microprogram control (MPU)--a method of control whereby each instruction is represented in the form of a set of microinstructions, i.e., hardware-implemented elementary machine operations.

Microprocessor (MP)--a central processor implemented by means of integrated technology utilizing one or more large-scale integrated circuits.

Microprocessor set, MP LSIC set--a set of compatible LSIC's for constructing microprocessors and microprocessor systems.

Microprocessor system (MP system)--a set of microprocessor processing, storage and input/output units used for implementing a single data conversion process. Also includes special software for arranging for combined operation and for controlling these units.

Minicomputer--a small computer having a broad application because of its small size and low cost. Its word length is from eight to 18 bits and most often 16.

Operand--input data element on which an operation is performed.

Debugging--process of detecting, localizing and eliminating software errors and hardware errors.

Peripheral equipment--equipment used for inputing data or outputing it from a computer, for arranging for the intermediate storage of data, and as an external storage.

User--in relation to an MP, the developer of an MP system; in relation to an MP system, the person involved in using it.

Program--a sequence of instructions determining the procedure for performing operations in the implementation of a specified algorithm.

Processor--unit for programmed processing of data in a computer.

Register--a storage employing switching elements (e.g., flip-flops), whose capacity usually equals one machine word. Designed for storing information in the process of processing data in a computer.

General-purpose register (RON)--the program-accessible operating register of a processor which can be used for on-line storage of various program elements.

Resident software--set of routines for creating and debugging the software of the computer on which this software is prepared.

Instruction set--the complete set of all instructions accessible in machine language of a given MP system or part of its structure.

Timer, clock--a clock pulse generator making possible the synchronous operation of all parts of the structure of an MP system.

Terminal--an external keyboard console for exchanging data with an MP system.

Flip-flop--an electronic logic circuit which assumes one of two possible stable states corresponding to 0 and 1.

Central processor--the central unit of a computer or computing system including an arithmetic unit, a control unit and operating registers. In addition to data processing, it also controls other units of a computer or system (e.g., peripheral equipment).

Line (data, address, control)--a line for coupling one or more sources with one or more receivers of information.

Assembly language--low-level programming language the structure of whose elements corresponds to instruction and machine language data formats.

Programming language--a formalized language designed for writing programs in a form recognizable by a computer.

Storage register--a register in a computer's storage to which access is possible through a specific address.

Chapter 1.

General Principles of the Organization of Microprocessors and Microprocessor Systems

1. Basic Elements of the Structure of a Microprocessor

The general structure of a microprocessor differs little from the structure of a computer processor of not too great capacity, of the class of the so-called minicomputers to which belong, e.g., the domestic M6000, SM-2 and SM-3 computers. Thus, knowing how a computer is built, it is quite uncomplicated to form an idea of the operation of a microprocessor. But knowledge of this kind, the ability to handle microprocessors freely, and in the end to use them effectively, are already now necessary for a much broader range of people than that of computer technology specialists. Obviously in the not too distant future there will not be a field of specialization involved in using electronic equipment which will not require knowledge of microprocessors.

Therefore, for the majority of readers of this brochure a first acquaintance with microprocessors can serve as the occasion for a deeper study of microprocessor equipment, which will help to become familiarized with their use.

The ability to program a sequence of functions to be performed, i.e., the ability to operate according to a specific program is the main difference of microprocessors from "hard" logic elements such as integrated circuits with a low and medium degree of integration, and this imposes certain conditions on their organization. First of all, in addition to the physical structure, called the hardware and forming the "body" of the microprocessor, there is software, personifying, so to speak, its "soul."

Of course there is a very close interrelationship between this "soul" and this "body" and only extreme simplification and sketchiness of the discussion make it possible to discuss them separately here.

And so, in the most general form the hardware of a microprocessor, imitating the structure of the central processor of a minicomputer, includes an arithmetic-logic unit (ALU), a control unit (UU) and several operating registers (R's). A microprocessor can contain from one to several chips, over which its structure is spread according to the criterion of functions performed (e.g., the ALU and R's on one chip and the UU on another) and/or according to the word length criterion (e.g., two ALU and R bits each on each of four chips and eight UU bits on a fifth chip form a five-chip eight-bit microprocessor).

Hence follows the definition, which has withstood fairly well up to the present time, of a microprocessor as a central processor implemented by means of integrated technology utilizing one or more large-scale integrated circuits.

This definition contains several important key points which require commentary. Firstly, it represents the hardware properties of a microprocessor as those of a processor and its element properties as those of an integrated circuit. Actually the appearance of the first microprocessors was the result of extreme simplification of the structure of the central processor of a computer to the level which could be realized by means of microelectronics with the level of integration reached up to that time.

Secondly, this definition makes it possible to consider a microprocessor only as a potentially universal data processing element, i.e., an element whose set of program-controlled functions makes it possible to implement basically any specific algorithm, since this is one of the main requirements for the central processor of a computer.

Thirdly, the definition gives the required composition of elements of the structure of a microprocessor, which according to the definition of a central processor includes an ALU, UU and R's.

In addition, the structure of an MP, i.e., in physical union with it, can include an input/output unit (UVV) for exchanging information between the microprocessor and other equipment, and also a clock (timer) and several other elements of the structure (fig 2).

Signals of three kinds--information, address and control--can be transmitted by one, two or three lines. A line represents a group of communication lines whose number determines the word length of binary information which can be transmitted through a line from one or more sources to one or more receivers. Lines are as a rule bidirectional, i.e., can transfer information in both directions.

Carrying through our analogy with a living organism, the system of lines in a microprocessor can be compared with the nervous system, whereby if processes in the information and address lines are similar to reflex activity, then processes in the control line are rather like activity of a higher level--like psychic activity.

The arithmetic-logic unit (ALU) performs various arithmetic and logic operations on numbers and addresses represented in binary code. Actually, the structure of these operations is determined by a list of instructions (instruction set) of the ALU, which comprise the "building material"--the basis of software for the MP as a whole.

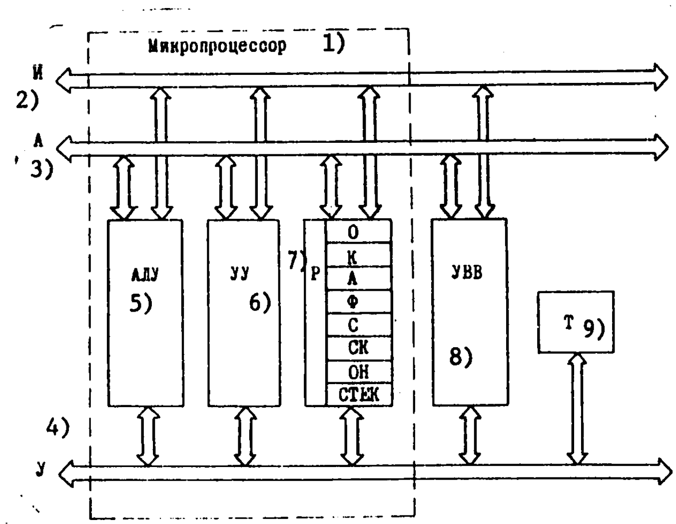

Figure 2. Generalized Structural Diagram of an MP with Three Separate Lines for Information (I), Address (A) and Control (U) Signals: ALU--arithmetic-logic unit; UU--control unit; UVV--input/output unit; T--timer; R--operating registers: O--for operands, K--for instructions, A--for addresses, F--flag, S--state, SK--instruction counter, ON--general-purpose, STYeK--stack

Key:

1. Microprocessor
2. I
3. A
4. U
5. ALU
6. UU
7. R's: O, K, A, F, S, SK, ON, STYeK
8. UVV
9. T

The instruction set of an ALU includes, as a rule, arithmetic and logical addition and multiplication, shifts, comparisons and the like. Arithmetic operations are performed according to the rules of binary arithmetic, which in principle differ in no way from the ordinary rules for addition, multiplication, carry, and other rules in the decimal system. Logic operations take place according to the rules of Boolean algebra (logic algebra), with which the reader can become acquainted, if desired, in [4], for example.

The structure of an ALU is fairly complicated but it does not contain any unique or specific elements; on the contrary, it uses a modulo-two adder, shifters, registers and other elements widely used in "hard" logic. The control unit controls the operation of the ALU and all other elements of the structure of the microprocessor.

In the control unit (UU) instructions arriving from the storage are converted into binary signals which directly act on all elements of the structure and stimulate execution of a given instruction. In addition, the UU, synchronized by the timer, distributes over time the process of the execution of an instruction. An instruction represents a binary word of eight, 16, 24 and more bits (up to 64), part of which represent the operation code and the remainder of which are distributed between the addresses of operands in the storage. In fig 3 is shown a 24-bit instruction word with a seven-bit operation code and two eight-bit addresses.

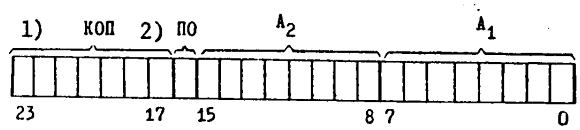

Figure 3. Twenty-Four-Bit Instruction Word
Bits: 17-23--operation code (KOP); 16--operand tag (PO); 8-15--address of second operand (A_2); 0-7--address of first operand (A_1)

Key:
1. KOP
2. PO

An instruction with a 16-bit address portion makes it possible to access $2^{16} - 1 =$ = 65,635 storage locations (it was necessary to subtract a unit since a mathematical address consisting of 16 zeros does not correspond to a physical location), and this number is as a rule completely sufficient for problems solved by a microprocessor in the structure of a microprocessor system. Such access to the memory is called direct addressing and is used less frequently than indirect addressing, which is necessary when the word length of the address portion is less than required. In this case addressing is performed in two steps: In the first step according to the address contained in the instruction a location is selected which contains the address of another location from which the operand is selected in the second step. With the indirect method of addressing an instruction must contain one operand tag bit, whose state determines what is selected in this step: the address of the operand or the operand itself. Of course the indirect method of addressing is slower than the direct. On account of the increase in the capacity of the address storage it makes it possible to access a 2^n-fold greater number of operands than with the direct method (n is the word length of the address section of the instruction).

The control unit distributes any operation according to the code specified by the instruction word into a sequence of phases--addressing phases and execution phases--called a cycle. Because of the limited word length of a microprocessor operations on operands of great word length can be performed in two cycles and more. Obviously this reduces the speed of the microprocessor twofold and more. From this can be drawn an interesting and important conclusion from the practical viewpoint: The speed of a microprocessor is inversely proportional to its accuracy, which is uniquely determined by the word length of operands (cf. sec 9).

The addressing phase begins with accessing, according to the address contained in the address register, A , the data storage, which is performed, as already mentioned, by the direct or indirect method, and ends with loading of the registers of two operands, O (cf. fig 2).

In the course of the execution phase in the ALU, according to the operation code, is completed an operation on operands read out from registers O , after which the result is entered in one of registers O called the accumulator. The contents of the accumulator, representing an intermediate result, are either used directly in the operation in keeping with the next instruction or are sent according to this instruction to the general-purpose register, ON , where they are stored until it is necessary to use them in the course of executing the routine.

All operations relating to the distribution of information, address and control signals between elements of the MP's structure, memory and peripheral equipment are accomplished by means of an input/output unit, UVV . The input/output unit represents a special-purpose microprocessor also called an input/output controller or an interface unit, and can be combined on a single chip with the MP per se or occupy a separate chip or several chips. The UVV has its own instruction set, i.e., is also program controlled and performs the functions of a unique "sense organ" of the microprocessor, enabling its communication with the outside world.

The aspiration of reducing the number of leads and increasing the useful area of a chip has resulted in the necessity of reducing the number of internal communication lines and contact areas, which occupy a considerable portion of the surface of a chip. This is made possible by transforming the parallel, i.e., existing and transmitted simultaneously, multibit binary code into a serial one, i.e., into a time sequence of signals, each of which corresponds to one bit of the original code, which makes it possible to transmit this sequence through a single line. The transmitted signals load the group of input registers of the data receiver in such a manner that with the arrival of the last they form the original parallel code, i.e., a reverse transformation takes place. This method of transmission of multibit information is called multiplexing.

Multiplexing is a forced measure caused by the need to reduce communications lines and limits the speed for the execution of input/output information instructions, and the more severely the greater the word length of the data transferred.

The operating registers of an MP physically represent identical storage locations serving the purpose of high-speed storage of running information (often they are united under a single name--a high-speed memory unit--an SOZU), but in terms of functions performed they are divided into groups associated with definite elements of the structure of the microprocessor.

The operand registers, O , during the time of the execution of an operation in the ALU store two binary numbers, one of which is replaced by the result upon termination of the operation, i.e., is accumulated, as it were; hence the register's name--an accumulator or accumulator register. The content of the second operand register is replaced by another operand in the next operation, while the content of the accumulator can be stored according to a number of special instructions.

The instruction register, K , stores several bits of the instruction word, which represent the code of the operation to be performed, during the time of its execution. The address portion of an instruction word is contained in the address register, A . After the execution of any operation the word length of the result can prove to be greater than the word length of each operand, which is registered by the state of a special flag register, sometimes called an overflow flip-flop. In the process of debugging a written program the programmer watches the state of the flag register and when necessary eliminates any overflow which originates.

Very important in the instruction set of a microprocessor are instructions for transfer to the execution of a specific section of a program in keeping with certain tags and conditions--so-called conditional transfer instructions. The presence of these instructions determines the level of "intellectuality" of a microprocessor, since it characterizes its ability to make alternative decisions and to choose various paths depending on conditions originating in the course of a solution. A special state register, S , serves the purpose of determining these conditions, which fixes the state of the MP at each moment of the execution of a routine and which sends to the control unit a signal for transfer to an instruction whose address is contained in a special register, not quite successfully called an instruction counter, SK . The point is that instructions are entered in the memory in a program-determined sequence according to addresses forming a natural series, i.e., the address of the next instruction differs from the address of the previous one by a single unit. Therefore, in the execution of a continuous sequence of instructions the address of the next instruction is gotten by adding one to the contents of the SK, i.e., is formed as the result of counting. But the purpose of the SK consists not so much in determining the number of instructions executed, as can be inferred from its name, as much as in finding the necessary instruction addresses, whereby with the presence in the routine of transfer instructions the next instruction may not have an address next in order. In this case the address section of the transfer instruction is entered into the SK.

The ON [general-purpose] registers are used for the purpose of storing intermediate results, addresses and instructions originating in the course of executing a routine and can be coupled through common lines with other working registers, as well as with the instruction counter and UVV. The number of ON registers in an MP usually does not exceed 10 to 16 with a word length of two to eight bits each and to a certain extent serves as an indirect indicator of the computing capabilities of an MP. A programmer can use these registers, accessing them through addresses, for the purpose of entering or recovering and transferring information to elements of the structure of the MP and to the memory.

Of special interest is the presence in many models of microprocessors of a group of registers having a magazine or stack organization--a so-called stack. A stack makes it possible without exchange with the memory to organize the proper sequence for the execution of arithmetic operations different in terms of precedence (a bracket has precedence over multiplication, multiplication has precedence over addition, and the like).

The organization of a stack is similar to the structure of a rifle magazine: The cartridge placed in the magazine first is shot last. An operand or other information can be sent to the stack without an indication of the address, since each word placed in the stack first occupies the first register and is then "pushed down" by subsequent words a register deeper each time. Information is read out in reverse order beginning with the first register in which was stored the word last sent to the stack, whereby the last registers are cleared.

The stack is loaded until the appearance in the first bit of an instruction which is of a lower order than or equal to the instructions in the stack. The appearance of this instruction serves as a signal for the ability to execute the entire sequence. The number of registers or levels ("depth") of a stack is an important characteristic of the structure of a microprocessor.

The depth of a stack can be increased considerably by organizing it not in the microprocessor itself, as is done in the description presented above, but in the memory. In this case in the registers (R's) is located a stack pointer register whose contents determine the address of individual storage locations in the working storage. The maximum number of levels of the depth of the stack depends on the word length of this address.

The structure of a microprocessor can include a timer, T , utilizing a mounted timing capacitor or a quartz-crystal resonator. The timer is the heart of the microprocessor, since its operation determines the dynamics of all information, address and control signals and synchronizes the operation of the UU, and by means of it of other elements of the structure also. The synchronization frequency, called the clock rate, is chosen to be maximum and is limited only by delays in the travel of signals, which are determined basically by the fabrication technology of the large-scale integrated circuit. The speed of execution of a routine by a microprocessor is directly proportional to the clock rate.

2. Organization of Memory; Structure and Operating Principles of a Microprocessor System

In sec 1 a brief description was given of the key elements of the structure of a microprocessor, of its hardware. From this description it is quite obvious that a microprocessor cannot operate without access to the memory for instruction words or to a stack organized there. However, the functions of the memory, which determine the structure and organization of storage units, ZU's, are not limited to sending to the microprocessor instructions and the contents of stack registers, but are much broader.

Storage units can be classified according to the characteristics and nature of functions performed. A diagram of such a classification is presented in fig 4.

All ZU's can be divided into two basic classes--external ZU's, having as a rule great capacity and not too high speed, and internal, i.e., structurally combined with the computing unit, of relatively not too great capacity, fairly fast acting and executed according to semiconductor technology.

External ZU's are power independent, i.e., the ability to store information in them resides in the structure of the medium. These media can be punched cards, punched tapes, magnetic drums, tapes and disks. Information is entered into them by a programmer and can be stored, forming libraries of various programs in the form of physical entities. The existence and completeness of these libraries is an important factor determining the possibility of the extensive use of computing systems.

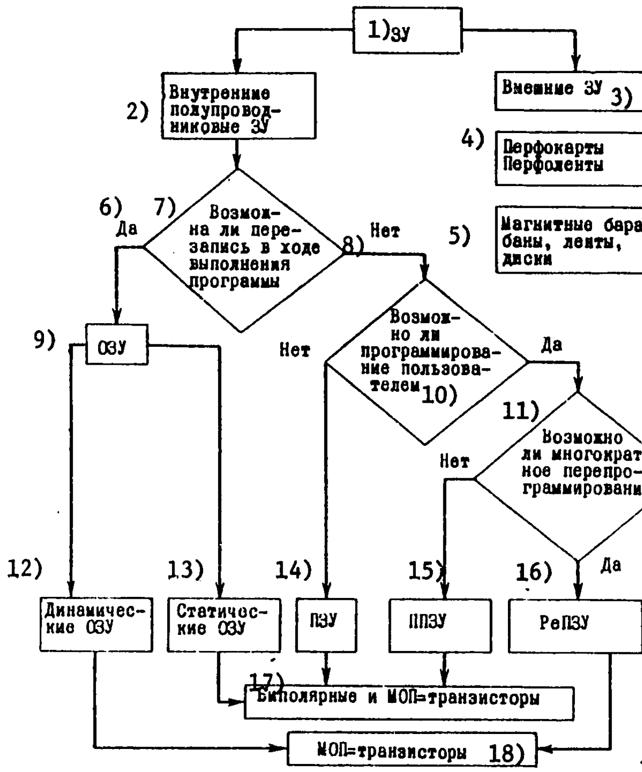

Figure 4. Classification Chart of Storage Units

Key:

1. ZU's [storage units]
2. Internal semiconductor ZU's
3. External ZU's
4. Punched cards, punched tapes
5. Magnetic drums, tapes, disks
6. Yes
7. Rewrite possible in course of running routine
8. No
9. OZU [RAM]
10. Programming by user possible
11. Repeated reprogramming possible
12. Dynamic OZU's
13. Static OZU's
14. PZU's [ROM's]
15. PPZU's [programmable ROM's]
16. RePZU's [reprogrammable ROM's]
17. Bipolar and MOS transistors
18. MOS transistors

internal ZU's occupy a bottom rung in the multilevel structure of a computer memory. This type of organization is very similar to the memory of a human being, in which it is also possible to distinguish two levels--the "permanent" memory, which is almost unerasable during one's life and is relatively slow because of its great capacity (recall the expression "rooted in one's memory") and the "short-term memory," whose contents are used in functioning and are replaced, and whose capacity is not too great. This analogy can be drawn even further, illustrating the evolution of the organization of ZU's as a deliberate but most often heuristic approximation to principles developed by nature.

Semiconductor ZU's are subdivided into working and permanent.

The group of working storage units (RAM's) makes it possible to enter information and read it out in the process of the execution of a routine. One and the same location can be used at various times for storing various information. The other group of semiconductor ZU's operates only for reading out, and in the course of a routine the contents of all locations remain unchanged. These ZU's are either programmed once and for all time by the manufacturer and come under the heading of permanent storage units (ROM's) or allow the possibility of entering information into them by means of special equipment, by the user, and come under the heading of programmable permanent ZU's (PPZU's).

The entry of information in a PPZU is based on irreversible processes and is accomplished by burning out the resistive links in bipolar or MOS transistor cells or, on the other hand, by shorting the cells by the masked spraying of conductors (the technologies for fabricating LSIC's are discussed in sec 4). A PPZU can also be executed on the basis of a special MOS structure. In this case the entry of information is accomplished by an electrical method on account of the storage of a static charge in a silicon inclusion isolated on all sides by an oxide and playing the role of an insulated gate with a trigger potential. The structure of such a cell is illustrated in fig 5.

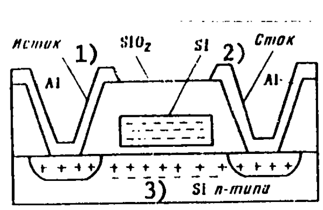

Figure 5. Structure of an n-MOS PPZU Cell with Static Charge Storage

Key:
1. Source
2. Drain
3. n-type silicon

The negative charge formed in the isolated silicon section forms on account of induction a positive region in an n-type channel, enabling gating of the MOS transistor. The charge drains for a very long time since the conductivity of the insulating oxide is vanishingly low. Existing PPZU's of this type store one-time-entered information about 10 years.

In the other case programming of the PPZU is acccomplished by burning out the links in the emitter circuits of bipolar transistors (fig 6a). Both methods require the use of special equipment.

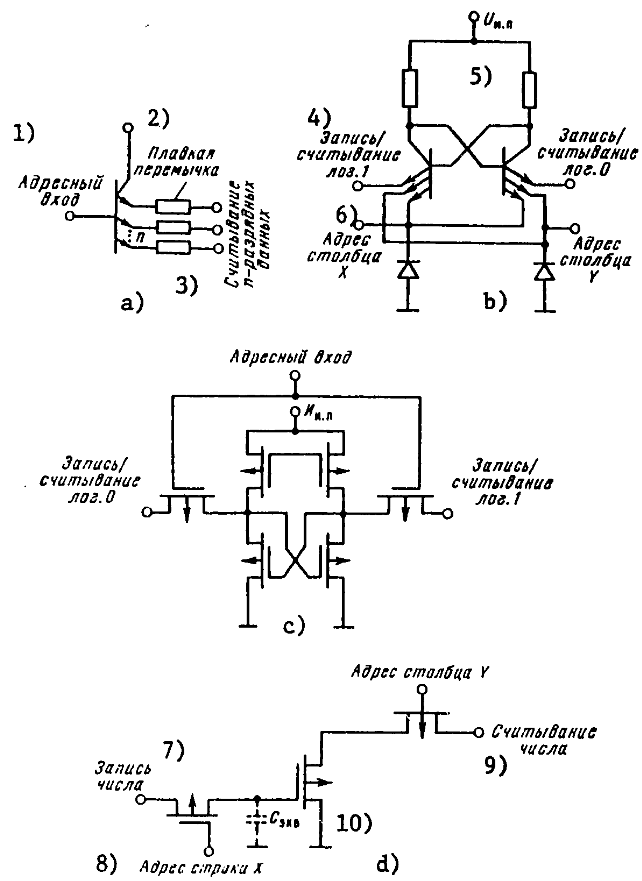

Figure 6. Circuit Diagrams of Storage Cells of Semiconductor Storage Units: a--cell of PZU [ROM] employing bipolar transistors with the entry of information by burning out fusible links; b--static bipolar OZU [RAM] cell; c--static OZU cell employing MOS transistors; d--dynamic OZU cell employing MOS transistors

[Key on following page]

Key:

1. Address input
2. Fusible link
3. Readout of n-bit data
4. Logical 1 readin/readout
5. $U_{i.p}$ [supply voltage]
6. Address of column X
7. Number readin
8. Address of line X
9. Number readout
10. $C_{ekv.}$ [equivalent]

Reprogrammable PZU's (RePZU's) make it possible to erase and rewrite information several times by means of ultraviolet irradiation of the cells shown in fig 5, directly, i.e., by methods of projection lithography or through a specially prepared mask. Among the disadvantages of these RePZU's must be named the considerable technological difficulties and the complexity of equipment for rewriting information. In addition the number of rewrites is limited as the result of a change in the electrical parameters of cells.

Working storage units are of the static and dynamic types. In the first the storage of binary information is caused by one of two stable states of a flip-flop executed with bipolar or MOS transistors (fig 6b and c). In dynamic OZU's information is stored on account of charging of the stray capacitance of an MOS transistor (C_{ekv}, fig 6d), approximately equal to 1 pF, during the time of its discharging through a leakage resistance equal to hundreds of megohms.

For the purpose of regenerating information it is read out and rewritten into the same cell from which it was read out over a period less than the discharge time. A special regeneration circuit makes this process possible. The use of a dynamic OZU somewhat reduces the overall speed since the operation of the microprocessor stops for the regeneration period.

It was mentioned in sec 1 that the cycle time of an MP system, on which speed depends to a considerable extent, can be determined both by the MP and by the memory, and more precisely by its key characteristic--the access time. In the overwhelming majority of instances it is precisely the access time which makes the greatest contribution to the length of the cycle; therefore, increasing the speed of the storage unit is regarded at the present time as one of the main ways of increasing the speed of the performance of operations.

In addition to access time, information capacity, power requirement and cost must be considered important characteristics of a ZU.

The values of these characteristics for various ZU's are presented in table 1.

Table 1. Characteristics of Semiconductor Storage Units

Fabrication technology	Type of ZU	Access time, ns	Information capacity, bits/chip	Power requirement, mW/bit	Relative cost
Bipolar	Static RAM	30-100	64-1K	5-0.5	High
	ROM	50-150	$\leq$ 16K	0.5-0.05	Low
	PPZU	50-150	$\leq$ 4K	0.5-0.05	Low

[Continued on following page]

MOS	Static RAM	200-500	256-1K	0,01-0,3	Medium
	Dynamic RAM	500	$\leq$ 4K	0,2-0,3	Medium
	ROM	350-1800	$\leq$ 16K	0,01-0,1	Low
	PPZU and RePZU	300	$\leq$ 16K	$<$ 0.1	High

The highest speed, as seen in table 1, is provided by bipolar static RAM's; however they have the lowest capacity and surpass all remaining kinds of ZU's in terms of the power required by a single cell. This has occasioned their use for the working storage of data, addresses and control signals in small MP systems processing relatively small amounts of information according to short routines.

Dynamic RAM's are slower than static, since they are executed on the basis of MOS technology, which generally loses to the bipolar technology with respect to speed. A feature of dynamic RAM's is the fundamental impossibility of working in the asynchronous mode, which is required when debugging programs by running them step by step. However, the advantages of great information capacity and low power requirement make it possible to make extensive use of dynamic RAM's in large MP systems.

Bipolar and MOS ROM's are used for storing constants, routines, subroutines of standards manipulations (such as sin , ln , multiplication table, code conversion, etc.), decoding instruction codes into a sequence of microinstructions, and microinstructions into a sequence of microoperations, as well as for setting up on the basis of semiconductor cells various combination circuits, such as a timer, buffer circuits and the like.

Bipolar ROM's differ from MOS by higher speed and a greater power requirement.

PPZU's and RePZU's are necessary where the modification or correction of routines are required.

The typical distribution of information depending on its nature between the external memory, ROM and RAM is presented in table 2.

Table 2. Typical Distribution of Information Depending on Its Nature Between External Storage, ROM and RAM

Type of storage	Contents of information stored
External storage	Routines entered by the operator, consisting of a sequence of addresses for the ROM
ROM, PPZU, RePZU	Constants, instruction (microinstruction set), standard manipulations, interrupt organizer
RAM	Sequences of addresses of instructions of a given program for the ROM entered from the external storage, intermediate data, stack, buffers for communication and exchange with external equipment

All information stored in the storage units comprises the software of the MP system, which is discussed in sec 7; here we dwell on the structure of an MP system and we also describe certain principles on which its organization is based.

Unlike a microprocessor per se, a microprocessor system already "knows how" to process information, i.e., to obtain the required result as the result of the computing process according to a specific routine performed on input data. Obligatory elements of an MP system are therefore a ROM, RAM and interface circuits. In addition, the structure of an MP system can include an external storage unit, as well as various peripheral equipment (fig 7).

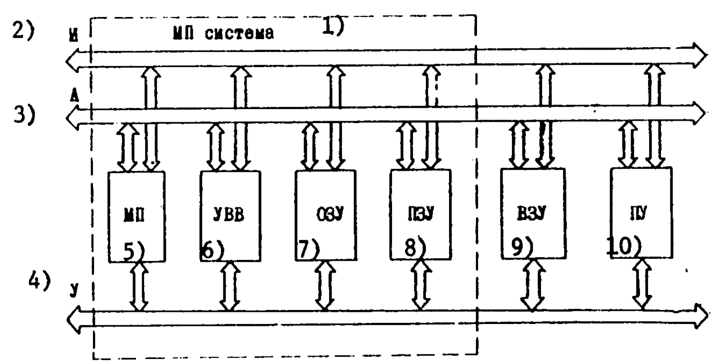

Figure 7. Generalized Structural Diagram of Microprocessor System: MP--microprocessor; UVV--input/output unit; OZU, PZU and VZU--working storage, permanent storage and external storage, respectively; PU--peripheral equipment

Key:

1.	MP system	6.	UVV
2.	Information	7.	OZU [RAM]
3.	Address	8.	PZU [ROM]
4.	Control	9.	VZU
5.	MP	10.	PU

Coupling of the elements of the structure of a microprocessor with one another, as well as their coupling with the RAM, ROM and peripheral equipment, is accomplished by means of an interface.

From the general definition of an interface presented in the introduction it follows that this concept includes the hardware for swapping data between parts of the system and a protocol describing the principles of the interaction of parts of the system in the process of swapping data.

In the case of an MP system the hardware of an interface is a large-scale integrated circuit with controllable functions such as, for example, a multimode buffer register (MBR), included in the structure of the K589 series, or an information exchange unit (OI unit) from the K587 series.

The principles of the organization of MP systems are described in greater detail in sec 21.

3. Bus Principle

The interface of an MP system has a bus organization. The bus principle is an almost necessary design principle for the structure of an MP system, since only thus is it possible to set up the exchange of information under conditions of the restrictions imposed by integrated technology.

What is the meaning of bus organization?

The exchange of information in a microprocessor and MP system whose structural diagrams are shown in figs 2 and 7 is organized in such a manner that there is a total of three multibit lines which implement all the required connections within the MP, as well as the input/output of data, addresses and control signals beyond its limits and beyond the limits of the MP system.

These lines replace an entire variety of necessary connections, since at each instant of time they connect only those elements of the structure for which the exchange of information is required at that instant.

The spatial distribution of interconnections in this case is replaced by a time distribution of connections of various sources and receivers of information through one and the same, in this case through three, communication lines. Telephone communications, for example, are organized similarly, where a great number of users can be connected through one and the same line, but not simultaneously.

Signals enabling exchange between specific elements of the structure of an MP or MP system are generated upon termination of the loading with information of the individual output registers and upon the clearing of individual input registers and last all the time until the line is occupied by other connections begun earlier or having priority over the one in question. This fact has a negative effect on the system's speed, but it is necessary to accept it, since bus organization is a strong means of making efficient use of the useful area of a chip on account of utilizing its surface, which, when the spatial separation of connections is employed, would be occupied by connecting wires and contact areas beneath a much greater number of external leads.

The connection of required elements of the structure to the bus line is accomplished by means of so-called circuits with three states. Two states are the usual logical 0 and 1 and the third--the high-output-impedance state--essentially means a cutoff as the result of which the circuit is disconnected from the line. The signal for controlling the third state is in fact the signal for permitting the reception and transfer of information through the bus line.

4. Interrupts

Microprocessor systems can swap information with a great number and varied combination of peripheral equipment. This includes displays utilizing cathode ray tubes for the graphic representation of data, printers, control switch panels, digital displays, magnetic tape, disk and drum storage units, relay switches, step motors, digital-analog (for output) and analog-digital (for input) converters and the like.

For the purpose of coupling with this equipment it is necessary to interrupt the operation of an MP system for the time required for exchange and to organize its operation according to a program making such exchange possible, after which it is necessary to again proceed to execute the working routine from the place where it was interrupted. In addition to enabling communication with peripheral equipment, interrupts serve the purpose of stopping the microprocessor at the end of a routine or upon a signal from the operator, as well as when executing an error instruction, and with overflow of internal registers or the RAM.

The executive program is interrupted upon a signal enabling an interrupt, which is generated either by an external unit directly, if it has been prepared to enter information into the microprocessor system, or in response to an interrogation signal sent from the microprocessor system if in the course of the execution of a routine the input or output of information is necessary. A subroutine for taking care of or organizing interrupts (a so-called input/output routine) is stored in the ROM and there can be more than one. The number of such subroutines determines the variety of equipment and of methods of swapping information with them. In this case one speaks of a vector interrupt, i.e., of an interrupt selected from a certain set of possible interrupts with an indication of the equipment attended to.

In the course of the execution of a subroutine servicing an interrupt the necessity can also arise of interrupting it for exchanging information with another peripheral unit having higher priority, after which it is necessary to return to the preceding interrupt and then to the executive program. The number of priorities or levels and also the presence of vector interrupts characterize the "communicability" of a microprocessor. The servicing of interrupts can be accomplished by means of a stack (cf. sec 1).

Some, especially the first, models of microprocessors did not have ready subroutines for servicing interrupts "protected" in the ROM, which forced the programmer each time, when the necessity for this became apparent, to arrange in the executive program for a halt and the exchange of information with input/output units. Multilevel vector interrupts make it possible to simplify programming and to improve substantially the utilization of work time by the microprocessor, excluding subjectivism in evaluating the need for an interrupt at a given step in the executive program. However, in a number of cases of using a microprocessor in a system there can also not be a need for interrupts.

A time diagram for the execution of three interrupts with various priorities and the change in the contents of stack registers when they are serviced are illustrated in fig 8.

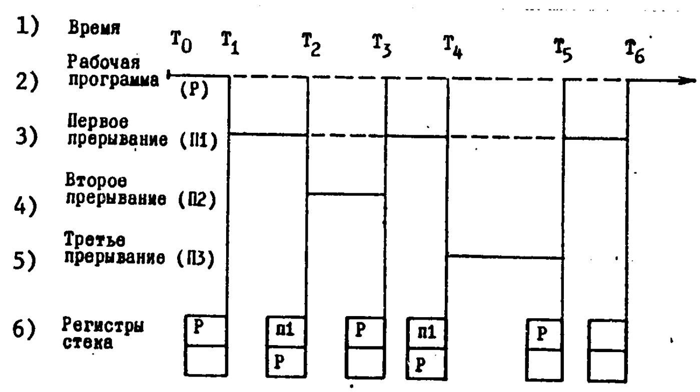

Figure 8. Time Diagram of Priority Interrupts When Using a Two-Register Stack: R--instruction word of executive program; n_1--instruction word of first interrupt routine

Key:

1. Time
2. Executive program (R)
3. First interrupt (P1)
4. Second interrupt (P2)
5. Third interrupt (P3)
6. Stack registers

In interval $T_0 - T_1$ the basic routine is executed, and as of instant T_1, corresponding to an interrupt signal with a certain priority, the upper register of the stack is loaded with an instruction word to which the routine must proceed if an interrupt is not to occur at this moment. The first interrupt is serviced until the arrival of a signal for the second interrupt, which has higher priority, whereby at moment T_2 the upper register of the stack is loaded with an instruction word from the routine for servicing the first, to which it is necessary to go in order to continue this routine. Upon termination of the second interrupt routine at moment T_3, this instruction word is selected from the stack (it arrived last and came out first--such is the "cleverness" of a stack!) and continues the first interrupt routine until the arrival at moment T_4 of the next interrupt, which also has higher priority. Upon termination of servicing of this interrupt at moment T_5 the execution of the first again continues, after which at moment T_6 a transition is made to execution of the main routine beginning with the instruction word written into the stack first. The stack is then completely cleared.

Thus, the longest first interrupt, having the lowest priority, was executed "piecemeal" in intervals $T_1 - T_2$, $T_3 - T_4$ and $T_5 - T_6$.

5. Direct Access to Memory

In the course of the execution of the executive program by a microprocessor system not infrequently the need arises to swap information between peripheral units and the RAM. This swap can be accomplished with the mediation of the microprocessor which, having interrupted execution of the executive program, in the course of a single cycle receives information from the peripheral unit (from the RAM) and during the next cycle transfers information to the RAM (to the peripheral unit).

The internal instruction, address and data registers of the MP in this case perform the role of an intermediate link for exchange with which an amount of time is spent equal at least to two cycles for each word transferred. In the transfer of great amounts of information this time considerably retards execution of the main routine. The ability to eliminate participation of the MP from the process of exchange between peripheral units and the RAM makes it possible to shorten the exchange time.

This possibility is afforded by a special unit--a memory-direct-access controller (PDP), which can be implemented both in the same chip as the MP and outside the MP by means of additional integrated circuits, a number of special instructions and a small number of additional RAM cells. The principle of a PDP is explained in simplified form in fig 9a and b.

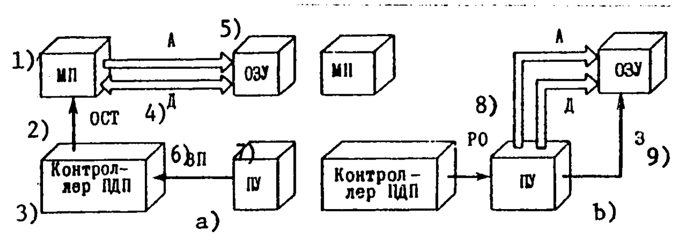

Figure 9. The PDP controller upon an interrupt enabling signal from the peripheral unit (PU) stops the operation of the microprocessor (MP) (a), after which the PU upon an exchange enabling signal (RO signal) is directly coupled with the RAM (b) and upon a write enable signal (Z) enters data (D) into the RAM according to address A .

Key:

1. MP	6. ZP [interrupt enable]
2. Halt	7. PU
3. PDP controller	8. RO [exchange enable]
4. D	9. Z
5. RAM	

The peripheral unit (PU), ready to readout information (this can be an external magnetic storage unit, for example), sends an interrupt enabling signal (ZP) to the PDP controller, which upon this signal selects the subroutine for servicing interrupts and, halting the operation of the MP (OST signal) connects the information (D) and address (A) buses to the input of the RAM and the output of the PU, enabling exchange between the PU and RAM (signal RO). During each cycle the RAM is addressed by an information word with a word length equal to the word length of the data bus of the MP. The write mode, corresponding to the transfer of data from the PU to the RAM, is determined by the write signal, Z .

The PDP controller can as a rule service the swapping of information between the RAM and several PU's whose ZP signals have been assigned different priorities. The following must thus be regarded as the main functions of the PDP controller: determination of the priority of the interrupt enable signal; interruption of the executive program executed by the MP; interruption of the subroutine for servicing the swapping of information of a PU with lower priority; generation of an exchange enabling signal and addressing of the peripheral unit; determination of the write/read mode; restoration of the course of execution of the executive program upon the termination of exchange.

The advantages of a PDP are especially important in the execution of routines involving the processing of large amounts of information according to relatively short algorithms, when the time spent on exchange between the PU and RAM is long as compared with the time for processing of data by the microprocessor. Meanwhile in a number of instances there is practically no need for a PDP; however, the aspiration of developers to satisfy the requirement of universality of use has resulted in the implementation of PDP's in the majority of second- and third-generation microprocessors.

6. Microprogram Control

In sec 1 in describing the structure of an MP it was noted that the control unit (UU) converts the operation code included in the instruction word into a combination of signals which act on all elements of the structure of the microprocessor and are necessary for the execution of this instruction. The UU thus accomplishes communication between the instruction storage and the processor section of an MP system by appropriate decoding of the operation code. The rules for this decoding are established by the developer of the MP and determine the internal structure and method of designing the UU.

Two approaches exist to organizing the control of microprocessors. The first, called software control, assumes the establishment in the design process of a unique correspondence bewteen a given code and a combination of actuating signals by the creation of improvised permanent connections between definite logic elements of the microprocessor. This approach is characterized by lack of a systems approach or by disorderliness of these connections and essentially means the lack of any structural principle in their design, which is traditional in the development of computing facilities of premicroprocessor generations.

The other approach, defined as microprogramming or microprogram control (MPU), assumes ordering of the design procedure and makes possible a definite system in designing the structure of the control unit (UU). The term "microprogram control" was introduced in 1951 by M. Wilks, who suggested this idea for the first time, and was defined by him as "a systematic and orderly approach to the design of a control unit for any computing system." This definition does not totally reveal all aspects of this method of control and rather indicates the aspiration of producing a theoretically substantiated principle as a historically created prerequisite for the origin of MPU.

In practice MPU has become a method of implementing a control unit whereby hardware control has been replaced by control based on the ROM programmed in a definite manner. Information is "protected" in the ROM in such a manner that in each operating cycle of the MP, corresponding to a single access to the ROM, a combination of logic signals is generated which controls one functional unit of the MP. From this it immediately follows that MPU assumes serial control distributed over time, which drastically increases the time for the execution of an instruction as compared with hardware control. This is perhaps the most important disadvantage of MPU which for a long time did not make it possible to gain broad acceptance because of the lack of a high-speed element base whose use could compensate the reduction in system speed.

From the viewpoint of the user of an MP system the presence of MPU in it means that each instruction perceived by the programmer as the expression of some single and completed action is broken down in the system into a series of microinstructions executed in turn and written in advance. The number and functional structure of the microinstructions of a microprocessor are determined by its internal structure and cannot be changed, but there is no need for this. It is much more important that on the basis of a strict microinstruction structure it is possible to create different instruction sets most adapted for the effective solution of specific problems in the sense both of the speed of solving them and of programming convenience, right up to the direct implementation by each instruction of the statements of a high-level language. With the employment of reprogrammable ROM's this property becomes the most important advantage of MPU, characteristic of implementation precisely in microprocessor systems. The user's capabilities are expanded in this case on account of the creation and addition to the microprocessor system of optimum instruction sets by the erasure from the reprogrammable ROM of previous information and the entering of new. The flexibility which can be acquired by a microprocessor system with MPU based on reprogrammable ROM's fundamentally makes it possible to realize in it any properties, such as software compatibility with another MP system, the employment of an arbitrary programming language, specialization in terms of speed, i.e., the ability to solve most quickly a specific range of problems, and the like.

Let us briefly discuss the principle of the organization of MPU in an MP system. In fig 10 is shown a general diagram of MPU which at first glance appears trivial. Actually, the address of the first microinstruction from the sequence implementing a single instruction is written in the microinstruction counter (SMK--analogous to the instruction counter in the MP structure). According to this address from the microprogram storage unit (MPZU) a microinstruction word is accessed, the word length, m , of which obviously determines the number of binary signals the combination of which via a microprogram decoder (DMP) directly controls the state of all elements of the MP's structure. In the DMP according to a tag contained in the microinstruction word a determination is made of the need to go to the following microinstruction of this instruction or to the first microinstruction of the next instruction if the last microinstruction has been executed. The address of the next microinstruction is formed in the counter by adding one to the address of the previous, or in the case of going to a new instruction upon a signal from the DMP by accessing the instruction storage unit with subsequent repetition of the entire sequence of operations described above.

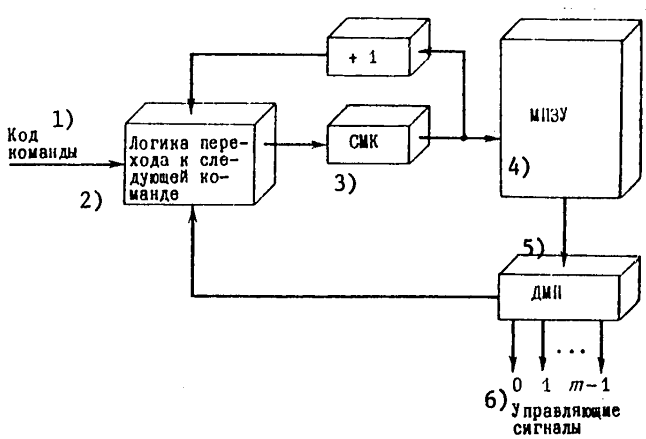

Figure 10. General Diagram of Microprogram Control: SMK--microinstruction counter; MPZU--microprogram storage unit; DMP--microprogram decoder

Key:

1. Instruction code
2. Logic for going to next instruction
3. SMK
4. MPZU
5. DMP
6. Control signals

Control according to this organization is carried out in two phases--the phase of accessing the MPZU and the phase of accessing the microprogram from the decoder's register. When using an MPZU, the access time to which is equal to the time for the execution of one microprogram, the execution phase can be combined with the phase of accessing the next microprogram. In this case control words are accessed from the decoder in each phase, which increases the speed of MPU.

In the simplest case an MPZU represents a logic array formed by a system of horizontal and vertical lines interconnected at points of certain intersections (fig 11). Each horizontal line corresponds to a single microinstruction and the number of vertical lines determines the word length of the control word. The number of horizontal lines (i.e., microinstructions) is limited by the word length of the microinstruction addressed, n , and cannot be greater than $2^n - 1$. For each address a single horizontal line corresponding to this address is brought into the state of logical 1 and this line in turn actuates all vertical lines having contact with it. The other horizontal and vertical lines are in the state of logical 0. The combination of 1's and 0's in the vertical lines forms the control word.

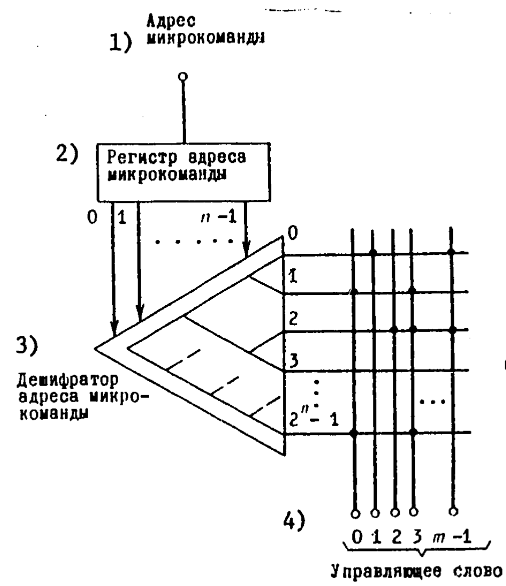

Figure 11. Microprogram Storage Array: n--word length of microinstruction address; m--word length of control word

Key:
1. Address of microinstruction
2. Microinstruction address register
3. Microinstruction address decoder
4. Control word

This array implements a logical OR function in the vertical lines, since for putting a vertical line into the 1 state contact only with a single horizontal line is necessary. Contacts with other horizontal lines in the state of logical 0 at this instant are of no significance.

A rather long word length (32 bits and more) is characteristic of a control word and the number of microinstructions can reach a few hundred. This results in the need of an MPZU of great capacity and compels developers to seek ways of using the microprogram storage economically.

The most interesting and effective method of economizing on storage capacity in producing microprograms is considered the use of a programmed logic array (PLM). Without going into the details of this rather complicated device, let us state that a PLM contains two arrays, the first of which implements an OR function in output lines and is similar to the one described above, and the second implements an AND function. The output of the first array is connected to the input of the second.

This design possesses broader capabilities than that presented in fig 11, and especially when implementing control in complicated systems. The high level of order in the structure of a PLM makes it possible to employ machine methods in designing it. In addition, on the basis of a PLM it is possible to create various structures similar in functions to the elements of "hard" logic, such as, for example, code converters, decoders and other elements widely used in microprocessor equipment.

7. Software

For a computer the term "software" unites the entire combination of information necessary for the effective functioning of the computer, as well as for formulating and solving specific problems on it.

In microprocessor technology this term has a somewhat broader meaning, since it also designates the facilities for designing the software and hardware of a microprocessor system based on microprocessor sets.

The information comprising the software can be stored in storage units or be represented in written form by means of specific formalizations representing programming languages, which will be treated below.

The software of an MP system (fig 12) makes possible the following: organization of the combined functioning of all elements of the structure of an MP system (operating system); the creation by the user of executive programs (programming, editing and debugging system); the utilization of the very programs accumulated in the process of their creation (library of applied programs); a check of the correctness of the functioning of an MP system and diagnosis of errors in its operation (check and diagnosis system); the designing of the software and hardware of an MP system based on MP sets by means of an external general- or special-purpose computing system (design automation system).

It is necessary to distinguish between the software of the MP per se and 6f the MP system. For the MP it is the instruction set of the MP, subroutines of standard manipulations and the like. Under this heading can be placed one or more executive programs if the MP functions as a controller and there is no need to change this group of programs. Access of the programmer to this software is limited and is occasioned only by the possibility of using a PPZU [programmable ROM] and an RePZU [reprogrammable ROM].

From the list of software functions given it is obvious that it includes programs both supplied by the manufacturer and developer of an MP system and programs written by its user.

Under the heading of the first comes a group of programs making possible functioning of the MP system, the combination of which is called the operating system, the programming, editing and debugging system which assists a programmer in writing executive programs, a system for checking and diagnosing the operation of an MP system and a design automation system making it possible to select for a given class of problems to be solved the optimum composition and structure of hardware and software of the MP system.

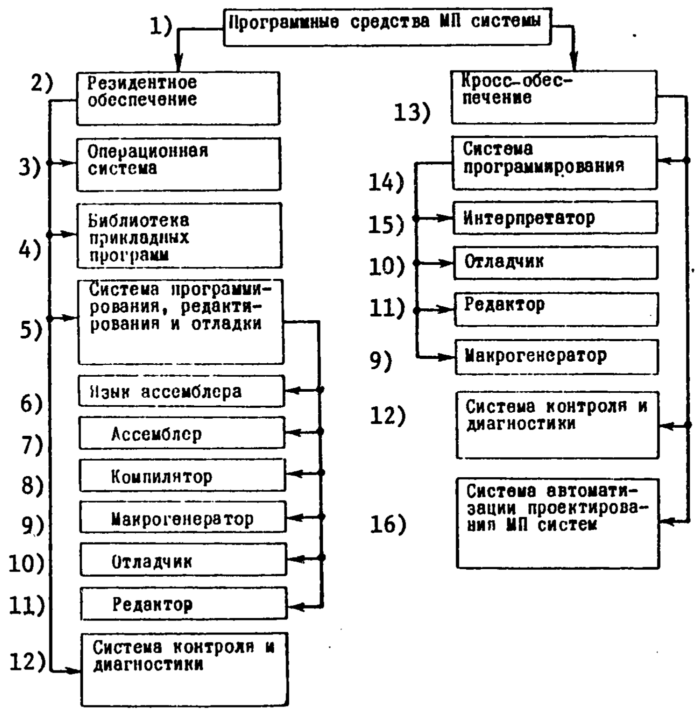

Figure 12. Simplified Structure of Software of an MP System

Key:

1. Software of MP system
2. Resident software
3. Operating system
4. Library of applied programs
5. Programming, editing and debugging system
6. Assembly language
7. Assembler
8. Compiler
9. Macrogenerator
10. Debugging routine
11. Editor program
12. Check and diagnosis system
13. Cross software
14. Programming system
15. Interpreter
16. MP system design automation system

The second group is formed by a library of programs accumulated as the result of using the MP system in question as well as other computing systems.

The possibility of using programs written for other computing equipment is realized by means of special translator routines which convert the codes of the programming language of this equipment into the codes of the MP system in question.

Programming languages stand out as intermediaries between human language (by means of the words and mathematical symbols of which it is possible to describe the combination and sequence of operations for performing any combination of computations) and a combination of binary codes directly recognizable by a computing system.

Programming languages are subdivided into levels by the degree of proximity to human language, i.e., by the ability to use them with minimum special training.

Without taking into account here the language of microprograms (microprogramming is discussed separately in the preceding section), the language of the lowest level must be considered binary codes, whose combinations form instructions recognizable by an MP system. Also able to be placed under the heading of low-level languages is the assembly language, which reflects features of the instruction set of a given MP system and is formed by a set of individual mnemonic codes.

We often encounter mnemonics, e.g., in the conventional symbols on the face panels of measuring instruments; the majority of road signs can be called mnemonic. The purpose of mnemonics is to facilitate the memorizing of a great number of symbols (for example, such as assembly language codes) by giving them forms associated with the content of the actions to be performed in relation to them.

Low-level languages are not general-purpose, since they can be used for writing programs only for the MP system for which they are developed. This creates serious difficulties, since a specialist working with different MP systems has to overcome the "language barrier" each time and software in binary codes or assembly language is not suited to various systems.

High-level languages are relatively general-purpose. Programs written in them do not depend on the structure of the instructions of the MP system in which they will be used. They also consist of a set of mnemonic codes, so-called statements, each of which can be implemented by a group of instructions in assembly language.

The most widespread high-level languages used for programming MP systems are FORTRAN-IV, BASIC and the specially created PL/M (Programming Language for Microprocessors--a programming language for microprocessors).

A program written in binary codes and in assembly language as compared with the same program in PL/M is illustrated in table 3 as an example of programming in different languages. According to the program the MP determines the lower of two numbers stored in memory locations X and Y, subtracts it from the larger, adds 5 to the result and sends the sum to location Z.

Table 3. Example of Program in Different Languages

Binary codes	Mnemonic notation of instructions in assembly language	Explanation
00 100 001 00 000 010 00 000 111	ABS LXIH 27	Accessing RAM according to address $10_2 = 2_{10}$ and $111_2 = 7_{10}$ contained in instruction counter for the purpose of reading the contents of cell X
01 111 110	MOVA, M	Writing contents of cell X into accumulator
00 100 011	INXH	Addition of one to address of cell X for obtaining address of cell Y
10 010 110	SUBM	Subtraction of contents of cell Y from contents of accumulator (i.e., obtaining difference X - Y in accumulator)
11 110 010 00 001 011 00 000 011	JP LOC	If $X - Y \geq 0$, a jump takes place according to address $1011_2 = 11_{10}$ and $0011_2 = 3_{10}$ to instruction LOC
00 101 111	CMA	If $x - Y < 0$, the sign of the contents of the accumulator is changed, which in binary arithmetic is achieved by substitution of all 0's and 1's and...
00 111 100	INRA	...adding one to the contents of the accumulator
11 000 110 00 000 101	LOC ADIS	Addition of $5_{10} = 101_2$ to contents of accumulator
00 100 011	INXH	Addition of 1 to address of cell Y stored in instruction counter for obtaining address of Z
01 110 111	MOVM, A	Writein of contents of accumulator into cell Z
11 001 001	RET	Routine completed. Return to executive program

PL/M High-Level Language

```
ABS: procedure;
Z = X - Y; IF  Z < 0  THEN  Z = -Z ; Z = Z + 5
RETURN
END ABS;
```

The instruction words in the first column are represented by an eight-bit binary code, and, as we see, several instruction words can correspond to a single code in the assembly language (second column). The content of the operations performed is explained in the third column.

In this example it is assumed that X, Y and Z are stored in the memory according to sequential addresses, i.e., the address of Y is obtained by adding one to the address of X and the address of Z by adding one to the address of Y. In the example with PL/M it is assumed that the addresses of locations X, Y and Z have been determined previously in the program.

Programming in a high-level language considerably shortens the time for writing and debugging programs (two- to fivefold for a program consisting of 200 instructions as compared with binary coding) and in many cases is the only acceptable method of programming. However, the advantages of programming of this sort must be paid for by an increase in the time for the solution of problems by the MP system (1.5- to threefold as compared with binary coding) and by the greater capacity of the memory required for this.

Software written in a low-level language which is continually tied to a given MP system and designed for use only with it forms so-called resident software. In addition to resident software there exists a large group of programs in the assembly language of the external computer or in a high-level language, called cross software. Cross software is intended for use in another computer and carries the same functions as resident software, with the exception of functions of the operating system, whose programs are "protected" in the ROM and external storage unit of the MP system. In addition, cross software includes the software of the design automation system, which makes it possible on the basis of a high-capacity external computer, using its software, to develop MP systems with properties closest to the class of problems to be solved.

The presence of a design system is the most important feature characteristic of MP equipment and makes possible the realization of the potential flexibility of an MP system, i.e., its adaptability to various problems on account of rearrangement of the structure and selection of the optimum composition of software on the basis of one and the same MP set. However, examples of the effective changing of the potential flexibility of an MP system into actual flexibility are still isolated.

Communication of cross software with resident, i.e., the translation of programs from high-level languages into binary codes of the instructions of the MP system, as well as the communication of the assembly language of the MP system with its binary codes, as already mentioned, is made possible by routines--translator routines included in the composition of the resident software.

One of the two kinds of resident translator routines--the so-called compiler--translates a program written in a high-level language into a program in the binary codes of the MP system, which in turn can be entered into the MP system for the purpose of obtaining the result of computations and can be used repeatedly without repeated compilation. Changing from the assembly language into binary codes is accomplished by the assembly routine--another kind of resident translator routine.

In cross software translation from a high-level language takes place by means of an interpreter and, if the assembly routine and compiler translate a program into a program, then the interpreter makes it possible immediately after its processing in the processor to obtain a result by means of an external computer. In other words, the interpreter, analyzing statements of the high-level language, directly performs the operations indicated in them by means of previously written subroutines included in the interpreter's structure; therefore secondary processing of the routine is not required, as is necessary for a compiler and assembly routine.

For the purpose of illustrating the functions entrusted to the components mentioned above and other components of the software of an MP system, let us discuss the programming process and its key steps which must be performed by a programmer on the way from the mathematical notation of the problem to its entry into the MP system for solution (fig 13).

The first of these steps is the writing of an algorithm, which can be considered the writing by means of mathematical symbols and necessary explanations of the entire sequence of conditions and operations corresponding to completion of the problem. Then a determination is made of the values or ranges of values of input data and of the structure of output data and an estimate is made of the time required by the MP system for solution.

The next step is the creation of a so-called flowchart. It represents a graphic representation of the logical relationships between certain conditions and the operations to be performed in keeping with them, the visualizability of which facilitates the further work of the programmer. Operations are usually designated by a rectangle and conditions by a diamond. A flowchart of the program presented in the example in table 3 is presented in fig 14.

Then a determination is made of the programming language, whereby the complexity of the problem, the required speed of solution and the capabilities of the storage are taken into account. The initial program is written in the language selected and is entered onto cards, by punching, for example, and is entered into the external storage.

Writing in the assembly language is facilitated considerably as the result of the use of so-called macrocodes. Each macrocode unites a group of serial codes in assembly language often encountered in the program, which makes it possible each time to replace the group of codes by a single macrocode. This makes it possible to reduce the probability of formal, i.e., associated with the form of writing, errors and speeds up the programming process. A special routine--the macrogenerator--processes macrocodes.

At the stage of processing of the original program by the MP system, after it is entered onto the medium, translation from the programming language into binary codes of the instruction set takes place. For this purpose an assembly routine or compiler is entered into the MP system as an executive routine and the codes of the original program are recognized by the system as input information. The result of translation is printed out with an indication of the formal errors committed in writing the original program. Errors are corrected by changing the punching of the individual cards and by repeated translation.

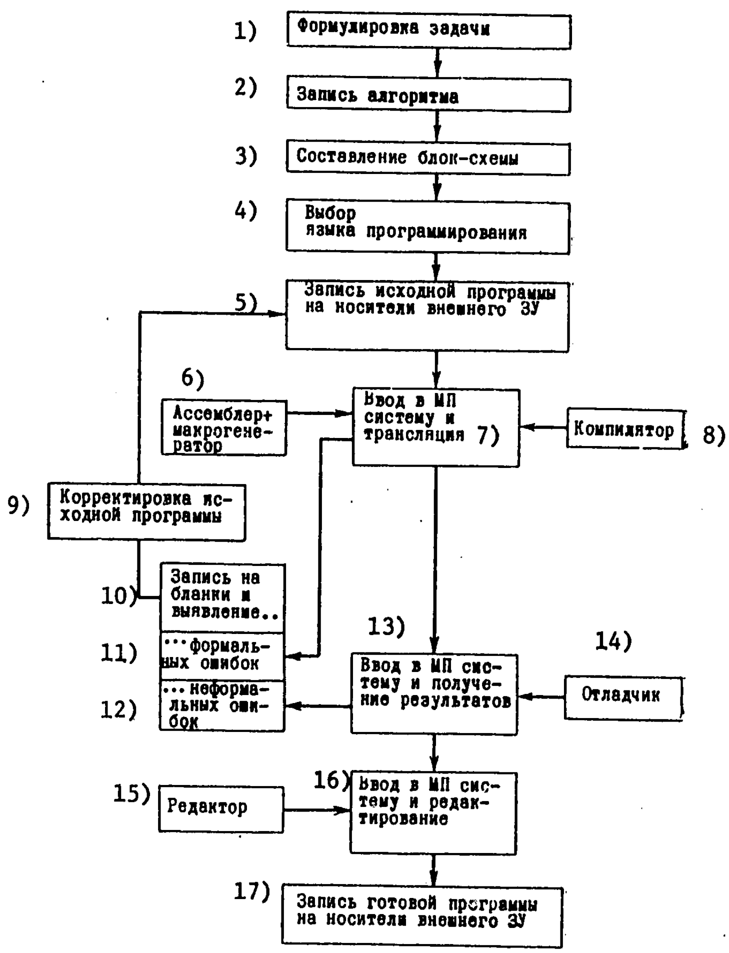

Figure 13. Main Steps in Programming by Means of the Internal Hardware and Software of an MP System

Key:

1. Formulation of problem
2. Writing of algorithm
3. Creation of flowchart
4. Selection of programming language
5. Writing of initial program on media of external storage
6. Assembly routine plus macrogenerator
7. Entry into MP system and translation
8. Compiler

[Continued on following page]

9. Correction of original program
10. Entry on forms and revelation of
11. Formal errors
12. Nonformal errors
13. Entry into MP system and obtaining of results
14. Debugging routine
15. Editor
16. Entry into MP system and editing
17. Writing of finished program on media of external storage

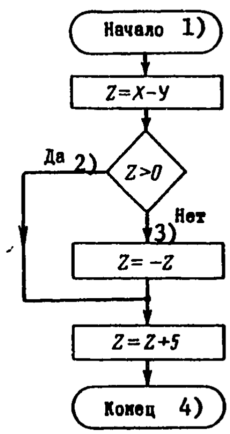

Figure 14. Flowchart of Program Presented in Table 3

Key:
1. Start
2. Yes
3. No
4. End

In addition, at this stage, if an assembly language is used, the processing of macrocodes takes place. The macrogenerator is entered into the MP system together with the assembly routine as an executive routine. After this by means of a special routine called the debugger the MP system makes it possible for the programmer to find and analyze errors of a nonformal nature, i.e., those which do not lead to those results which are expected from the completion of the problem posed, which can be the result, for example, of an incorrectly selected algorithm or of an improperly constructed flowchart. The debugger makes possible the printing out of instructions executed and the contents of necessary sections of the RAM at specific moments of execution of the program.

The required corrections are also entered onto punched cards with the original program, which following this again undergoes translation and debugging. This cycle is repeated until a completely debugged program is obtained, which can be only part of the total original program, since it, as a rule, for the purpose of the simplification of writing and debugging, has to be broken down into several relatively independent parts which can be translated and debugged by turns.

The individually written and debugged sections are united into a single whole by means of an editor--a program which puts into order the links between them according to the general flowchart. The editor sees to logical links and their sequence and their distribution in the memory.

The program produced in this way, written on the media of the external storage unit, is ready for work and can be stored in the library of applied programs for future use.

Chapter 2.

Characteristics of Microprocessors Determining the Diversity of Their Areas of Application and Application Features

8. Technological and Circuitry Methods of Fabricating Large-Scale Integrated Circuits

The technology of the fabrication of large-scale integrated circuits has embodied all the best accumulated by semiconductor technology in the nearly 30-year history of its development.

At the present time the main material for integrated microcircuits is monocrystalline semiconductor silicon, whose quality, i.e., the minimum presence of impurities and the flawless nature of its structure, have to a considerable degree determined the ability to increase the integration of integrated circuits fabricated.

The technological process of fabricating LSIC's includes a complicated combination of operations whose composition and conditions of execution are basically different for the two kinds of technology. The first--the bipolar technology--is based on the use of bipolar transistors, and the second--MOS (metal-oxide-semiconductor) technology--on the use of transistors with a field effect.

Large-scale integrated circuits fabricated by the bipolar technology differ in turn by the circuitry methods of implementing them, of which there are chiefly three. They include transistor-transistor logic with Schottky diodes (TTLSh), integrated injection logic (IIL or I^2L) and emitter-coupled logic (ECL). In the MOS technology it is possible to distinguish between four circuitry methods of implementing LSIC's: an MOS device with p-type- or n-type-channel conduction (p-MOS or n-MOS), and also a complementary MOS device (CMOS device) and a modification of it utilizing semiconductor silicon on a sapphire substrate (CMOS/SOS (silicon-on-sapphire) device).

By p-MOS circuitry it was possible for the first time to arrange on a silicon chip with an area of 10 mm^2 2000 to 3000 logic elements required for organizing a complete program-controlled structure--the very simple type 4004 processor manufactured for the first time by the Intel firm (USA) in 1971. Then n-MOS circuitry reached the required level of integration, somewhat surpassing p-MOS in terms of speed with the same power requirement.

A basic logic element simultaneously employing p- and n-channel MOS transistors served as the basis for creating an MP [microprocessor] LSIC employing CMOS circuitry, whose characteristics in combination are already considerably better than in previous types of circuitry. The use of a sapphire substrate in CMOS/SOS-type circuitry has made it possible to reduce approximately twofold delays in the switching of logic elements, i.e., to improve their speed.

Representing a considerable advance in the pursuit of speed is the achievement of the integration required for creating LSIC's by means of the bipolar semiconductor technology; whereas TTLSh and ECL have been known for a comparatively long time, I^2L was invented in 1972 simultaneously in the USA and FRG and immediately found application in the fabrication of LSIC's.

The basic logic elements of CMOS, TTLSh, I^2L and ECL devices are shown in fig 15a to 15d.

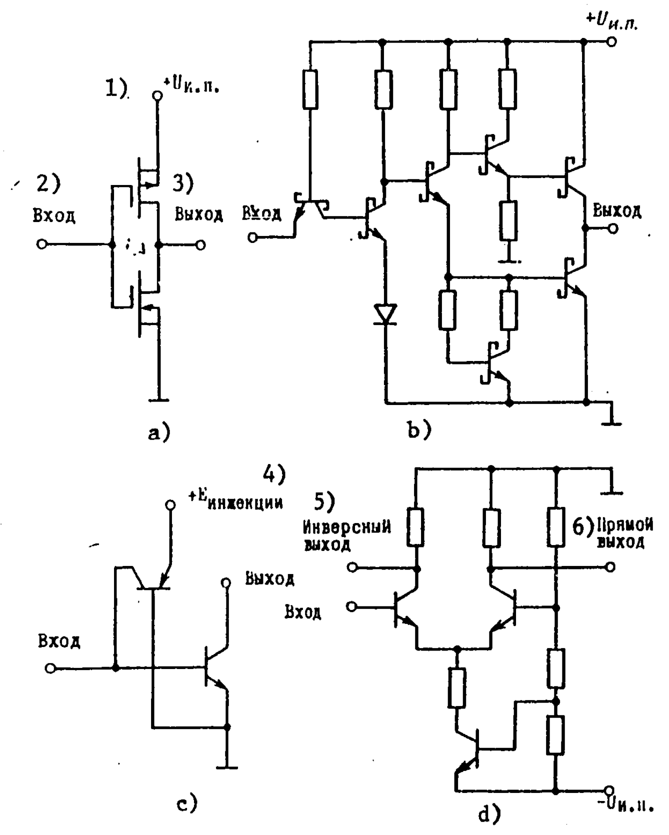

Figure 15. Diagrams of Basic Logic Elements of CMOS (a), TTLSh (b), I^2L (c) and ECL (d) Devices

[Key on following page]

Key:

1. Supply voltage
2. Input
3. Output
4. Injection
5. Inverse output
6. Direct output

The characteristics of circuitry methods of fabricating MP LSIC's are discussed in their relationship to MP characteristics in sec 9; here we make a comparison of their capabilities in terms of the switching delay time of a single logic element and of the power required by it.

The product of the delay by the power consumption is called the switching work and characterizes the degree of ideality of the circuitry and the process of its improvement in terms of approaching the theoretical limit, which for silicon integrated circuits is estimated approximately at 10^{-15} J. Dependences of the speed of response of logic elements executed by various circuitry methods on the power requirement are presented in fig 16. Let us note that for p-MOS, I^2L, TTLSh and ECL the switching work depends but slightly on the speed of response and power and can be considered constant over a small range. On the other hand, for n-MOS and CMOS devices the switching work depends wholly on the power requirement and the speed of response is constant. Figure 16 also illustrates the limits of the capabilities of a specific circuitry approach. From it it is obvious that CMOS circuitry is closer than others to the theoretical switching work limit, however it does not make it possible to achieve a switching delay of less than a few dozen nanoseconds. I^2L circuitry has the broadest range of variation of delay and required power, but its speed of response is not better than that of CMOS circuitry. p-MOS and n-MOS logic elements make possible the same delay as I^2L, but with a higher power requirement, i.e., have a higher value of the switching work.

The fastest responding, as follows from fig 16, are elements designed according to TTLSh and ECL circuitry and they are the most powerful. As we see, each kind of circuitry has a preferred area of its utilization with regard to speed of response which is overlapped by others with the exception of p- and n-MOS devices, which are gradually displaced by I^2L, which have lower switching work.

In considering the entire combination of significant characteristics of MP LSIC technologies, including, in addition to speed of response and power requirement, level of integration, noise immunity, number of supply voltage levels, adaptability to streamlined manufacture, cost, and the like, it can be said that each of them has the right to exist and to further improvement of the advantages inherent in it.

In addition to the improvement of existing methods, an intense search is under way for new technological and circuitry methods of implementing LSIC's which will enable greater integration and less switching work of logic elements. Logic elements whose operation is based on the use of the Gunn effect, as well as on the Josephson effect, are considered promising at the present time. A new modification of the MOS technology has already found an application--the so-called V-MOS technology--making it possible to increase integration considerably by increasing the useful area of a chip by using in it a surface with V-type recesses. The possibility of using gallium arsenide as a semiconductor material for fabricating LSIC's is considered promising.

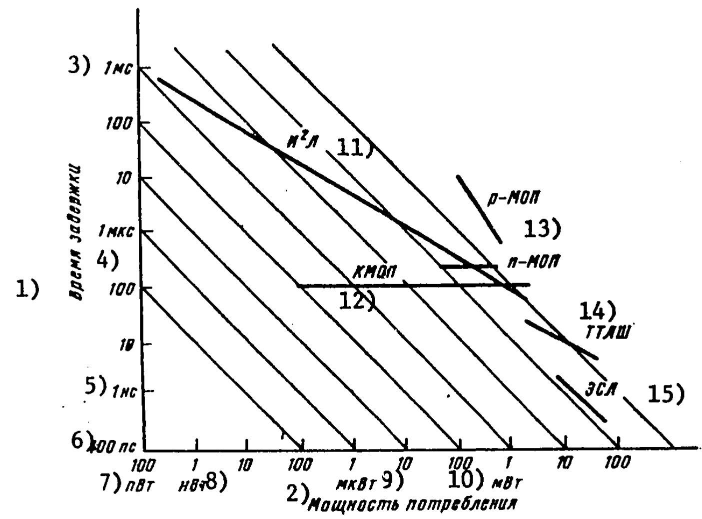

Figure 16. Comparison of Ranges of Variation of the Speed of Response and Power Requirement of Logic Elements Designed by Various Circuitry Methods

Key:

1.	Delay time	9.	μW
2.	Power requirement	10.	mW
3.	ms	11.	I^2L
4.	μs	12.	CMOS
5.	ns	13.	p-MOS
6.	ps	14.	TTLSh
7.	pW	15.	ECL
8.	nW		

9. Characteristics of Microprocessors as Large-Scale Integrated Circuits

The presence in microprocessors of element and apparatus properties determines the composition of the parameters characterizing them. The system of parameters or characteristics of a microprocessor, the combination of which determines the most effective area of application and the aspects of the development of systems based on it, should obviously include characteristics inherent in both digital electronic computing facilities and in integrated circuits. The key characteristics of a microprocessor and their relationships to the internal and external structure (architecture) and the integrated technology of a microprocessor are presented below. Some of these characteristics were already discussed in ch 1 in describing the general principles of the organization of microprocessors and others are considered from the viewpoint of estimating them in selecting the area of the most effective application of a microprocessor.

The following are the key characteristics of a microprocessor inherent in electronic digital computing facilities and determined by the internal and external structure: word length, capacity of addressable memory, number of internal registers, bus principle and microprogram control, possibility of interruption and number of interruption levels, presence of stack organization and number of stack registers, presence and composition of resident and cross software, universality (specialization).

The key characteristics of microprocessors inherent in integrated circuits and determined by the integrated technology are the following: speed of response, power requirement, overall size and weight, compatibility with TTL and number of power supply levels, reliability, stability of performance and cost.

10. Speed of Response

In the most general sense the speed of response of microprocessors, as of any digital piece of computing hardware also, is defined as the mean speed of the execution of a certain algorithm, whose instruction makeup represents a mixture reflecting the specifics of the class of problems to be solved. Mixtures for various classes of problems are put together on the basis of a statistical generalization of the instructions of all algorithms characteristic of a given class. A Gibson mixture, by means of which it is possible to compare the speed of response of various pieces of computing hardware when scientific and technical problems are solved by them, and other mixtures exist, for example. However, it is necessary to take into account the fact that the value obtained in this manner is of an averaged nature and can differ from the value obtained for a specific problem.

Because of the difficulty of a quantitative determination of speed of response in the sense cited above, in practice a less general but more intelligible simplified concept is used. The concepts of cycle time and clock rate, indirectly related to speed of response, are also used.

Most often the speed of response of a microprocessor is characterized by the time for or speed of execution of the brief operation of adding the contents of a register, R , to the contents of an accumulator with the subsequent copying of the result into a register, R (an operation of the RR type), although other definitions are also encountered in the literature. However, the comparison of microprocessors in terms of speed of response in the sense cited cannot be considered correct in a random case and, moreover, not infrequently results in errors. The point is that algorithms for tasks to be performed reflecting the specifics of the tasks themselves can contain a various amount of operations of the RR type, the time for the execution of which is used as the speed of response in a given case. In addition, the microprocessor itself can be oriented, as already mentioned, to the execution of various algorithms in which the density of the addition operation can be practically any.

Thus, from the speed of execution of the RR operation it is possible to make a judgement only on the speed of response of universal microprocessors, and it is possible to compare according to this characteristic only functionally identical microprocessors when the same problem is solved by them.

The cycle time or access time is the term customarily used for the period of time spent by a microprocessor for accessing a single word in the memory. This time can be determined by the speed of response both of the microprocessor itself and of the storage unit.

The clock rate is the frequency of the clock pulse generator, either external or included in the structure of the microprocessor set, which the time delays of the microprocessor's signals synchronized by the generator make possible to assign. A different number of microoperations, the time for the execution of each of which can be different, is executed during a single cycle in various microprocessors; therefore, it is possible to use the clock rate, and the cycle time, too, only for a qualitative estimate of the speed of response, paying attention to the facts indicated above.

The speed of response can be judged in part from the circuitry and fabrication technology of a microprocessor, since they determine the time delays of logic elements forming the structure of a microprocessor. As was already indicated, the speed of response increases in the order of logic circuits implemented on the basis of employing the following types of circuitry: p-MOS, n-MOS, CMOS, CMOS/SOS, I^2L, TTLSh and ECL, i.e., each type of circuitry in line provides greater speed of response than the preceding. Rough values of speed of response characteristics of microprocessors are presented in table 4.

Table 4. Rough Values of Speed of Response Characteristics, Power Requirement and Degree of Integration of Various Microprocessor LSIC's

MP characteristics	MP LSIC circuitry						
	p-MOS	n-MOS	CMOS	CMOS/SOS	I^2L	TTLSh	ECL
Time for execution of an operation of the RR type, μs	4-10	4-6	2.5-6	2-2.6	1-1.5	1-0.5	0.1 and less
Speed of execution of operations of the RR type, million operations/s	0.1-0.25	0.25-0.18	0.18-0.4	0.38-0.5	0.7-0.1	1-2	10 and more
Cycle time, μs	0.7-5	0.5-4	0.12-1	0.01-0.1	0.2-1	0.1-0.2	0.01-0.1
Clock rate, MHz	0.2-1.5	1-2	1-3	10-100	1-5	5-10	10-100
Power requirement, W/chip	0.6-1.0	0.75	0.01-0.2	0.1-0.3	0.8	2-3	Up to 5
Degree of integration achieved, gates/mm^2	90	110	45	100	150	25	25

As we see, an objective and universal estimate of the speed of response of a microprocessor is a quite complicated matter and convenient and sufficiently universal criteria practically do not exist for it up to the present time.

11. Power Requirement, Overall Size and Weight

Such a characteristic of a microprocessor as the power requirement is important for questions relating to application. The power supply occupies a considerable portion of the space and weight of a large class of devices implemented with integrated microcircuits. The changeover from low- and medium-degree-integration integrated circuits to LSIC's for microprocessors will make it possible, having maintained the speed of response, to reduce more than twofold the power requirement, overall dimensions and weight, which will considerably expand possibilities for the application of computer hardware. In simple MP systems with a low speed of response, where the power requirement is not high and the overall dimensions and weight of the power supply are less substantial as compared with the overall dimensions and weight of the MP LSIC, the gain with regard to these characteristics in changing over from low- and medium-degree-integration integrated circuits is from five- to 20-fold. As mentioned in sec 8, the product of the power of a logic element and its speed of response is an approximately constant value for integrated circuits of the p-MOS, I^2L, TTLSh and ECL type and a reduction in power is possible only at the expense of a reduction in speed of response. The power dissipated by the elements of an LSIC chip imposes a limitation on the degree of integration and requires additional measures relating to the removal of heat from the chip. Therefore, whereas for micropower MOS and I^2L circuitry the degree of integration is limited by the size of a unit cell and the useful area of the chip, for integrated circuits of the TTLSh and ECL type the limitation imposed by the dissipated power and the ability to remove heat from the chip is important. This fact is illustrated by the two bottom lines of table 4, in which are indicated rough values of the power requirement and degree of integration of microprocessors for various technologies.

12. Compatibility with Transistor-Transistor Logic; Number of Power Supply Levels

Mention must be made of such properties of a microprocessor determined by the technology as the required number of supply voltage levels and the compatibility of logic levels with the most widespread TTL levels. A single-level power supply makes it possible to manage with a simpler stabilized power supply and compatibility with TTL levels eliminates the need for level converters when microprocessors operate with peripheral equipment or with one another.

Values of supply voltage levels and data on the compatibility of logic levels of microprocessors for various types of logic are presented in table 5.

13. Word Length

The word length of a microprocessor, or the length of one of its information words, which is the same thing, indicates what number of binary digits (bits) of information can be processed simultaneously by the processor.

Table 5. Values of Supply Voltage Levels and Data on the Compatibility of Logic Levels for Various MP's

MP characteristics	Circuitry of MP						
	p-MOS	n-MOS	CMOS	CMOS/SOS	I^2L	TTLSh	ECL
Supply voltage levels, V	+5 -12	+5 -5 -12 or just +5	3-15	3-15	1-5	+5	-2 -4 to 5.2
Compatibility with TTL	No	Yes	Yes	Yes	No	Yes	No

The accuracy of computations obviously depends on the word length. For example, a word length of four bits makes possible a maximum error of 12.5 percent, of eight bits 0.8 percent, of 12 bits 0.05 percent and of 16 bits 0.003 percent.

In addition to accuracy, the word length in a number of cases determines the speed of response, since with a word length of the processor less than the length of an information word stored in the storage unit the processing of information is carried out in serial portions with the expenditure of time for two or more accesses to the memory.

Greater word length of a microprocessor requires a greater number of leads and increased integration of LSIC's. At the same time the useful area of a chip used for accommodating elements is reduced considerably with an increase in the number of contact areas under leads; therefore, the creation of an MP with a great word length is limited by the capabilities of integrated technology.

A way out has been found by creating so-called processor sections with an expandable word length, whose leads make it possible to unite them for the parallel processing of data and to obtain thereby a word length which is a multiple of the word length of a single processor section. Optimization of the word length is thereby achieved, i.e., the elimination of redundancy which is possible in using microprocessors with a fixed word length, and the ability to obtain a great word length (24, 32 bits and more) is also made possible.

In addition, the greater number of external leads of a combination of processor sections makes it possible to organize for them a greater number of connections with storage units and external units, to eliminate multiplexing which reduces speed of response, and to increase the number of interrupt levels for internal and external signals, i.e., to organize a more ideal and faster responding interface, which is especially important for the operation of a microprocessor as part of a system.

14. Capacity of Addressable Memory

The capacity of the addressable memory characterizes the ability to utilize the microprocessor in a system from the viewpoint of the greatest volume of information which can be processed and is determined by the word length of the address line, making it possible to accomplish the copying of the address of information or a necessary instruction. For example, when using a 16-bit address line the addressing of up to 65,535 storage cells ($2^{16}-1$) or almost 64 Kbits of information (1 Kbit = 2^{10} = 1024 bits) is possible.

15. Reliability and Performance Stability

Reliability, i.e., the ability to operate for an extended period under specific conditions without failures, is almost the same in a microprocessor as in an integrated circuit with a low and medium degree of integration and is considerably higher than in equipment of functional complexity similar to that of a microprocessor and uniting in its structure hundreds of integrated circuits.

Generally speaking, the reliability of semiconductor (monolithic) integrated circuits does not depend directly on the number of elements making them up, and the elements themselves can be isolated only hypothetically. The circuit diagram of an integrated circuit reflects the features of the topology of a single chip and does not testify to the presence in it of individual transistors, individual resistors and individual connections between them. Therefore, the probability of failure is determined chiefly by the useful area of a chip, i.e., is proportional to the probability of the occurrence of a defect in the structure of the chip. The high degree of integration making possible the creation of LSIC's for microprocessors is achieved chiefly on account of reducing the dimensions of unit cells of the integrated structure and of improving the quality of silicon, which has made it possible to bring the area of a chip from five to 10 to 25 to 50 mm^2 without considerable worsening of the reliability of LSIC's.

The reliability of equipment employing integrated circuits is determined to a considerable degree by the quality and number of internal interconnections. In systems employing microprocessor LSIC's the number of connections has been reduced to a minimum, which has chiefly been responsible for their higher reliability.

As with reliability, the stability of microprocessor LSIC's under the influence of utilization factors is not worse than in integrated circuits with a low degree of integration, and with regard to many kinds of influences is greater than in equipment employing integrated circuits.

Especially important is the lack of the need for the servicing of MP systems for an entire series of applications (in addition to high reliability this is also the consequence of relatively low cost). This makes it possible to use MP's widely over an entire range of permissible utilization influences, i.e., under conditions in which their work cannot be replaced directly or checked by a human being. Microprocessor systems have undisputed advantages over any other control, diagnosis and data gathering systems for working in chemically active media and under conditions of abnormal temperature, humidity, pressure, vibration, acceleration and ionizing radiation, i.e., everywhere where the presence of a human being is excluded or the taking of protective measures is required.

16. Classification of Microprocessors; Key Characteristics of Foreign Microprocessor Sets

The characteristics discussed in chs 1 and 2 make it possible to classify microprocessors in terms of the most important of them for the purpose of selecting the effective area of application. One possible variant of such a classification is presented in fig 17.

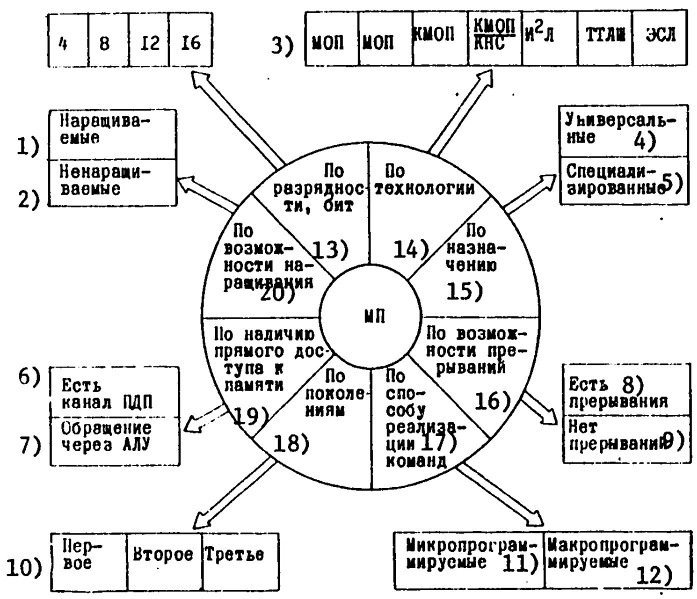

Figure 17. Classification of Microprocessors

Key:

1.	Expandable	11.	Microprogrammable
2.	Nonexpandable	12.	Macroprogrammable
3.	MOS, MOS, CMOS, CMOS/SOS, I^2L, TTLSh, ECL	13.	By word length, bits
4.	Universal	14.	By technology
5.	Special-purpose	15.	By purpose
6.	Is a PDP [memory direct access] channel	16.	By possiblity of interrupts
7.	Access via ALU	17.	By method of implementing instructions
8.	Are interrupts	18.	By generation
9.	No interrupts	19.	By presence of direct access to memory
10.	First, second, third	20.	By possibility of expansion

Microprocessors can be divided into two groups in terms of purpose: universal, i.e., making it possible together with other LSIC microprocessor sets to create microcomputers for a wide range of applications. Able to serve as the clearest example is the domestic series K580, as well as the MCS-80 MPK [microprocessor set] of the Intel firm, which has become the world standard for systems of this type;

special-purpose, the important difference of which from universal microprocessors consists in the lack of a need for developed software. A typical example of a special-purpose MP is calculator LSIC's.

The specialization of MP's in the sense proposed here in no way contradicts the definition of an MP as a potentially universal data processing element. The instruction set of a special-purpose MP includes all instructions required for implementing any prescribed algorithm; however, for certain special problems its abilities with regard to speed of response are greater.

Microprocessors are divided into micro- and macroprogrammable in terms of method of implementing instructions or method of control.

Microprogram control, as already mentioned in ch 1, makes it possible for the user to establish his own set of instructions (commands) which are optimum for the implementation of certain specific tasks. This makes a microprocessor the most "flexible," i.e., makes it possible to adapt it to the maximum to solving a wide range of problems and, in addition, makes it possible to interpret the architecture of various computers by employing their software.

Macroprogram (strict hardware) control in principle does not permit this possibility, but is more economical and as a rule enables higher speed of response.

Microprogramming is thus especially necessary for universal microprocessors designed for a wide range of applications; however, it is necessary to mention again that the realization of the potential advantages of the microprogram principle of control requires changing the microinstruction set, involving the fabrication of a new microprogram memory LSIC, which requires considerable input of time and money and is not always convenient for the user. In recent times the trend has been noted of the more effective utilization of the possibilities of microprogramming by using a reprogrammable ROM inside the MP, which makes it possible to rewrite information by the electrical method or to erase by means of ultraviolet rays with subsequent writing by means of electrical signals, as, for example, provided for in the model 8748 microprocessor from the Intel firm.

The increasing needs of users with regard to ensuring maximum universality have exerted the main influence on selection of the method of controlling a microprocessor. For example, early models of microprocessors, even such popular ones as the Intel 4004, 4040, 8008 and 8080, the Motorola (USA) MS6800, the RCA COSMAC (USA), do not have microprogramming, which is typical of later models of microprocessor sections with an expandable word length, such as the Intel 3002, the Texas Instruments (USA) SBP0400 and the domestic series K589, K587 and K584.

The possibility of interrupts is an inherent property of a universal computer and is lacking in a number of microprocessor models, chiefly on account of the aspiration of simplifying the external structure, which has been dictated by the inadequate capabilities of integrated technology.

The presence of direct access to the memory (PDP) makes it possible to increase the speed of response of an MP system by direct rapid exchange (bypassing the ALU) between the storage unit and external units and is made possible by the structure of the LSIC's of the majority of existing microprocessor sets.

On the basis of requirements for the accuracy of computations and taking into account the above-mentioned influence of the word length on speed of response, the optimum length of an information word of an MP for a specific area of application is selected or its physical variation is provided for by employing microprocessor sections. A relationship exists between the word length of a microprocessor and real applications [2, 6].

The relationship between the characteristics of a microprocessor, including speed of response, and the possibility of a specific application is illustrated in greater detail in sec 23. Table 6 illustrates an example of this relationship.

Table 6. Example of Relationship Between Word Length of MP and Real Applications

Word length of MP, bits	Preferred area of application
4	Arithmetic units of measuring instruments (multimeters, oscillographs, etc.) Simple controllers, technological and household automatic machines, games
8	"Intellectual" terminals Control of technological processes Controllers Testing equipment Transportation control Service, business, trade and household equipment
16	Communications systems Data gathering systems Analog-digital converters Monitoring and distribution systems (water, gas, fuel, electric power) Navigation systems Broad-application microcomputers
20-32	Communications systems Digital filters Fourier transformers Autocorrelators Broad-application micro- and minicomputers

By analogy with generations of computers, three of which occupied about 30 years and the fourth is considered the generation of computers whose element base is LSIC's, including microprocessor LSIC's, in many publications the evolution of microprocessor technology from the period since 1971 through the present time is associated with three generations of microprocessors [7-10]. Membership in each of them is determined by a combination of traits, including fabrication technology, speed of response, word length, features of structure and architecture and development of software.

The first generation of microprocessors (1971-1973) is characterized by the most simple p-MOS technology, a four- to eight-bit word length and low speed of response (the time for executing an operation of the RR addition type is about 10 μs). They have the simplest structural organization and the least large instruction set, numbering 45 to 60. The addressable memory capacity is as a rule not great and software is limited. Typical representatives of first-generation microprocessors--microprocessors of the Intel 4004, 4040 and 8008 type--are produced up to this time, since because of their low cost and their technical characteristics they meet the needs of many areas of application.

To the second generation (1973-1975) belong microprocessors manufactured according to the n-MOS technology, which has made it possible to increase speed of response considerably (the time for executing an operation of the RR type is about 2 μs). These microprocessors have a word length of 8 to 16 bits, a more developed instruction set and an improved structure and software. Among the disadvantages of second-generation MP's must be named the need for the majority of MP types for a three-level supply voltage, whereas two levels are sufficient for first-generation MP's. The most popular second-generation models have become the Intel 8080, the Fairchild Semiconductor F-8 and the Motorola (USA) MC6800.

Third-generation microprocessors have been fabricated according to CMOS, CMOS/SOS, TTLSh, I^2L and ECL circuitry. They have a fixed word length of 8 to 16 bits or an expandable word length which is a multiple of 2, 4 or 8 bits, medium or high speed of response and an improved structural organization and instruction set. Microprogram control, the presence of a built-in channel for direct access to the memory and developed software are characteristic of them. Their technical characteristics, owing to the various technologies, vary considerably and lie within the following ranges: The time for executing an addition operation of the RR type is 0.1 to 1 μs, and the dissipated power is 10 to 2000 mW. They have a single supply voltage level. Typical representatives of third-generation microprocessors are the Intel 3002, the Intersil (USA) IM6100, the Monolithic Memory (USA) MM6701, the Texas Instruments SBP0400, and the Intel 8748/8048, 8085 and 8086.

The key characteristics of some of the most popular foreign MPK's [microprocessor sets] are given in table 7.

Chapter 3.

Domestic Microprocessor Sets

Let us discuss here the key characteristics of three MPK's developed and mastered in production by domestic industry--the series K580, K587 and K589.

The composition of the sets and their technical characteristics are summarized in table 8.

17. Series K580

The K580 series includes six large-scale integrated circuits fabricated according to n-MOS circuitry, which make it possible to construct 8-bit general-purpose and special-purpose MP systems with a very broad range of application. Universality of the set is due to a considerable extent to the functional completeness of the large-scale integrated circuits making it up, which include: a K580IK80 8-bit microprocessor (MP); a K580IK55 program-controlled interface for peripherals (PPI); a K580IK51 program-controlled interface for communications channels (PSI); a K580IK57 memory direct-access controller (KPDP); a K580IK53 program-controlled interval timer (DVI); and a K580IK59 priority interrupt controller (KPP).

Table 7a. Key Characteristics of First-Generation (p-MOS) Microprocessors

		20) Технические характеристики						21) Особенности структуры						22) Программное обеспечение				
Модель микропроцессора (фирма-изготовитель, страна)	Год выпуска	Число кристаллов МП	Время выполнения операции сложения, мкс	Тактовая частота, МГц	Мощность потребления, Вт	Диапазон рабочих температур, °С	Уровни напряжения питания, В	Разрядность информационного слова, бит	Емкость адресуемой памяти, К	Стек (количество стековых регистров)	Возможность прерываний (число уровней)	Прямой доступ к памяти	Микропрограммное управление	Резидентное обеспечение	Кросс-обеспечение	Транслятор с языка высокого уровня	Система редактирования и отладки	Моделирующие программы
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
AMI 7300 (American Microsystem, США) «Америкэн Микросистем»	1973	2	4	1	0,8	—20 +80	+5 —12	8	64	(32)	(4)	+	—	—	+	—	+	—
PPS-25 (Fairchild, США) «Фейрчайлд»	1973	4	62,5	0,4	0,6	0 +70	+5 —10	25×4	6	(4)	—	—	—	—	+	—	+	—
4004 (Intel, США) «Интел»	1971	1	10,8	0,75	1	0 +70	+5 —10	4	4	(3)	—	—	—	—	+	—	+	+
4040 (Intel, США) «Интел»	1974	1	10,8	0,75	1	0 +70	+5 —10	4	8	(7)	+	—	—	—	+	+	+	+
8008 (Intel, США) «Интел»	1972	1	20	0,5	1	0 +70	+5 —9	8	16	(7)	(8)	—	—	+	+	+	+	+
IMP-16 (National, США) «Нэшэнл»	1973	5	4,6	0,7	1,4	0 +70	+5 —12	16	64	(16)	(1)	+	+	+	+	+	+	+
PPS-4 (Rockwell, США) «Роквелл»	1973	1	5	0,2	0,23	—55 +125	—17	—17	4	(4)	(2)	—	—	—	+	—	+	—

Key:

1. Model of microprocessor (manufacturing firm and country)
2. Year of manufacture
3. Number of microprocessor chips
4. Time for executing an addition operation, μs
5. Clock rate, MHz
6. Power requirement, W
7. Operating temperature range, °C
8. Supply voltage levels, V
9. Word length of information word, bits
10. Capacity of addressable memory, K
11. Stack (number of stack registers)
12. Possibility of interrupts (number of levels)
13. Direct access to memory
14. Microprogram control
15. Resident software
16. Cross software
17. Translator from high-level language
18. Editing and debugging system
19. Simulation programs
20. Technical characteristics 21. Features of structure 22. Software

Table 7b. Key Characteristics of Second-Generation (n-MOS) Microprocessors

Модель микропроцессорного комплекта (фирма-изготовитель, страна)	Обозначение собственно МП (ЦПЭ) в комплекте	Год выпуска	20) Технические характеристики					21) Особенности структуры					22) Программное обеспечение					
			Время выполнения операции сложения, мкс	Тактовая частота, МГц	Мощность потребления, Вт	Диапазон рабочих температур, °С	Уровни напряжения питания, В	Разрядность информационного слова, бит	Емкость адресуемой памяти, К	Стек (количество стековых регистров)	Возможность прерываний (число уровней)	Прямой доступ к памяти	Микропрограммное управление	Резидентное обеспечение	Кросс-обеспечение	Транслятор с языка высокого уровня	Система редактирования и отладки	Моделирующие программы
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	13	19
F-8 (Fairchild, США) «Фейрчайлд»	(F-3850)	1974	2	2	0,6	0 +70	+5, −12	8	64	(RAM)	+	+	+	+	+	+	+	+
CP-1600 (General Instrument, США) «Дженерал Инструмент»	CP-1600	1974	3	5	0,75	0 +70	+12 +5, −5	16	64	(16)	(4)		+	+	+	+	+	+
MCS-80 (Intel, США) «Интел»	8080	1974	2	2	1	0 +70	+12 +5, −5	8	64	(RAM)	+	+	−	+	+	+	+	+
MC 6800 (Motorola, США) «Моторола»	MC6800	1974	2	1	0,25	0 +70	+5	8	64	(RAM)	+	+	+	−	+	−	+	−
TMS-9900 (Texas Instrument, США) «Техас Инструмент»	9901	1975	1,3	3	1,2	—	+12 +5, −5	16	64	—	(15)	+	+	+	+	+	+	+
2650 (Signetic, США) «Сигнетик»	2650	1974	4,8	1,2	0,5	0 +70	+5	8	32	(8)	(1)	+	−	−	+	−	−	+

Key:

1. Model of microprocessor set (manufacturing firm and country)
2. Designation of microprocessor per se (central processing element) in set
3. Year of manufacture

4-22. [cf. table 7a]

Table 7c. Key Characteristics of Third-Generation Microprocessors

Модель микропроцессорного комплекта (фирма-изготовитель, страна)	Обозначение собственно МП (ЦПЭ) в комплекте	Год выпуска	21) Схемотехника	Технические характеристики: Время выполнения операции сложения, мкс	Тактовая частота, МГц	Мощность потребления, Вт	Диапазон рабочих температур, °С	Уровни напряжения питания, В	22) Особенности структуры: Разрядность информационного слова (наращиваемая), бит	Емкость адресуемой памяти, К	Стек (количество стековых регистров)	Возможность прерываний (число уровней)	Прямой доступ к памяти	23) Микропрограммное управление	Программное обеспечение: Резидентное обеспечение	Кросс-обеспечение	Транслятор с языка высокого уровня	Система редактирования и отладки	Моделирующие программы
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AM2900 (American Micro Dewice, США) «Америкэн Микро Девайс»	(2901)	1975	TTLSh	0,1	10	0,93	—55 +125	+5	(4)	64	—	+	+	+	+	+	+	+	—
3000 (Intel, США) «Интел»	(3002)	1975	TTLSh	0,1	8	0,75		+5	(2)	0,5	—	(8)	+	+	+	+	+	+	+
MCS-48 (Intel, США) «Интел»	8043 или 8748	1976	n-MOS	2,5	2	0,4	0 +70	+5	8	64	+	+	+	—	+	+	+	+	+
MCS-80 (Intel, США) «Интел»	8086	1977	V-MOS	1	5		0 +70	+5	16	1000	+	+	+	—	+	+	+	+	+
M 6100 (Intersil, США) «Интерсил»	6100	1975	CMOS	2,5	8	0,01	—55 +125	4—11	(12)	4	+	+	+	—	+	+	+	+	+
MM6700 (Monolitic Memory, США) «Монолитик Мемори»	(6701)	1975	TTLSh	0,2	5	1,12	0 +70	+5	(4)	64		+	—	+	+	+	+	+	+
MC 10800 (Motorola, США) «Моторола»	(10800)	1975	ECL	0,05		1,3	0 +0,85	—2 —5,2	(4)	64	—	+	+	+	—	+	+	+	+
COSMAC (RCA, США) «Эр Си Эй»	—	1975	CMOS	6	2,67	0,01	—55 +125	4—11	(8)	64	—	+	+	—	+	+	+	—	—

Key:

1. Model of microprocessor set (manufacturing firm and country)
2. Designation of microprocessor per se (central processing element) in set
3. Year of manufacture
4. Circuitry

5-23. [cf. 4-22 in 7a and 7b]

Table 8.

Characteristics of MPK	Series K580	K587	K589
Composition of set	K580IK80--MP [microprocessor] K580IK55--PPI [program-controlled interface for peripherals] K580IK51--PSI [program-controlled interface for communications channels] K580IK57--KPDP [memory direct access controller] K580IK53--DVI [interval timer] K580IK59--KPP [priority interrupt controller]	K587IK2--AU [arithmetic unit] K587RP1--UP [control memory] K587IK1--OI [information swapping unit] K587IK3--AR [arithmetic expander]	K589IK01--BMU [microprogram control unit] K589IK02--TsPE [central processor element] K589IK03--SUP [fast carry circuit] K589IK12--MBR [multimode buffer register] K589IK14--BPP [priority interrupt unit] K589AP16--ShF [line driver] K589AP26--ShFI [inverting line driver]
Circuitry	n-MOS	CMOS	TTLSh
Word length (expandable), bits	8	(4)	(2)
Time for execution of addition operation, μs	2	2	0.1
Clock rate, MHz	2	0.5	8
Power requirement, mW	1000 (MP)	10 (AU)	750 (TsPE)
Operating temperature range, °C	-10 to +70	-60 to +80	-10 to +70
Capacity of addressable memory, Kbits	64	64	0.5
Stack	RAM	No	No
Possibility of interrupts (number of levels)	(8)	Yes	(8)
Direct access to memory	Yes	Yes	Yes
Microprogram control	No	Yes	Yes

In addition, together with the LSIC's listed it is possible to use without any kind of interfaces four microcircuits from the series K589 MPK--K589IR12, K589IK14, K589AP16 and K589AP26.

The K580IK80 LSIC is an 8-bit central processor unit designed for use as an information processing element in MP data processing and control systems. The instruction set is fixed, the total number of instructions is 78 and the levels of input and output signals are compatible with the most widespread TTL levels. A chip measuring 4.2 X 4.8 mm contains about 5000 transistors and is enclosed in a 48-terminal case.

The structure of the K580IK80 LSIC matches almost totally the structure presented in the generalized structural diagram of an MP (cf. fig 2) and described in sec 1. The only difference is that this LSIC does not contain stack registers but makes it possible to organize a stack memory in the RAM. For this purpose among the LSIC's registers there is a special 16-bit stack pointer which makes it possible to arrange a magazine-type storage in any area of the RAM and makes it possible to service an unlimited number of subroutines.

The arithmetic-logic unit is a parallel 8-bit unit which performs key data processing operations.

The control unit (UU) generates control signals required for the execution of instructions in the MP. The basis of the structure of the UU is the principle of a programmed logic array.

The LSIC's registers include: two 8-bit operand registers (O); an 8-bit instruction register (K); a 16-bit address register (A); an overflow flag register (F); four single-bit state registers for indicating sign, carry, parity and zero (S); six 8-bit general-purpose registers (ON); a 16-bit stack pointer; and a 16-bit instruction counter (SK).

Interfacing is made possible by three separate bus lines for transmitting data (I), addresses (A) and control signals (U). Line I is 8-bit. Line A is 16-bit and makes it possible to address 64 Kbits of memory, as well as 256 inputs and 256 outputs of external units. The control line makes possible synchronization of the operation of the MP, external storage and input/output units, as well as control of servicing of interrupts and of direct access to the memory and the output of information on the state of the MP.

In addition to the elements of the structure listed, in the LSIC are concentrated 30 TTL buffers for operation with external circuits.

The K580IK80 LSIC is characterized by high adaptability to streamlined manufacture, relatively low cost and a sufficiently universal structure making it possible to use it widely for constructing MP systems both together with other LSIC's of the K580 MPK series and independently.

The K580IK55 LSIC is designed for organizing the parallel exchange of information between an MP system and peripheral units. It includes an 8-bit buffer register for connection to the data line of the MP system, three 8-bit registers for communication with the inputs/outputs of peripheral units, and a control unit connected to the control and address lines of the MP system. Control signals specify the operating mode (write or read) and a 2-bit address determines the peripheral unit with which exchange will take place.

The structure of the LSIC is based on the use of circuits with three stable states (cf. sec 3). Employment of the K580IK55 LSIC eliminates the need for additional logic circuits, which makes it possible to consider it a complete and sufficiently universal external interface element permitting the possibility of independent application.

The K580IK51 LSIC can also serve as an example of an interface element, but this LSIC, unlike the foregoing, receives and transfers information not in parallel (i.e., all bits of an information word simultaneously), but serially, bit by bit.

This need exists in the transmission of data over great distances, when it is not possible to use multiwire communications lines, e.g., in distributed control at an industrial enterprise, in transmitting digital information through a telephone line, etc. The K580IK51 LSIC converts a parallel binary code into a serial one in transmission and completes reverse conversion in reception. The length of a word of data is 8 bits.

The K580IK53 LSIC serves the purpose of producing time delays of programmable duration. It contains three independent 16-bit counters whose scaling factor is determined by a program, as well as a circuit for controlling the operating mode and buffer registers for storing 8-bit data.

The problem of generating precise time delay signals for a specific number of operating cycles is often encountered when an MP system performs an operating routine. Such a delay can be implemented through software, having organized in the operating routine the execution of a so-called "time loop," i.e., a cyclically repeated "idling." The use of the K580IK53 LSIC makes it possible to free the programmer of the necessity of encumbering a program with these cycles by means of access to one of three program-controlled counters through a special instruction.

If the delay made possible by the 16 bits of one counter is insufficient, it can be increased by adding the bits of the other two counters.

In addition, the K580IK53 LSIC can be used as: a clock pulse counter; a binary multiplier; a real-time pulse generator (hours, minutes, seconds, etc.); and an electronic motor rotational velocity regulator.

The K580IK57 LSIC is designed for organizing in an MP system the exchange of information between the storage and peripheral units, bypassing the MP. This exchange procedure is described in sec 5; here it is necessary to add that this LSIC organizes exchange through four channels having different priorities, and data are entered and read out in parallel.

The K580IK59 LSIC is an 8-level priority interrupt controller. The functions of this controller are described in sec 4, and the distinctive features of this LSIC lie in the ability to increase the number of priority interrupt levels to 64 by uniting it with LSIC's of the same type.

18. Series K587

The series K587 microprocessor set contains four LSIC's fabricated according to the CMOS technology and is designed for constructing on their basis various pieces of computer hardware with a speed of response on the order of 100,000 to 200,000 operations per second and with an ultralow power requirement.

The software developed specially for this MPK includes both resident and cross software making it possible to design microcomputers with broad functional capabilities--universal and oriented to a specific range of special problems. In addition, there is the ability to use the set's LSIC's independently in terms of their functional purpose as independent digital information processing modules or ones built into the equipment. Important features of this MPK are the microprogram principle of control and the ability to expand the word length by uniting several 4-bit processor sections.

The set's hardware includes the following LSIC's: a K587IK2 arithmetic unit (AU); a K587RP1 control memory (UP); a K587IK1 information exchange (OI) unit; and a K587IK3 arithmetic expander (AR).

Strictly speaking, it is impossible to call a microprocessor any one of the LSIC's listed above taken individually. An MP can be formed here as the result of uniting by means of an OI interface LSIC two components--AU and UP LSIC's containing in combination all the elements of the structure of an MP.

Characteristic features of AU, UP and OI LSIC's are the microprogram principle of control, as well as the ability to operate (including the AR LSIC, too) in the asynchronous mode, which makes possible, for example, implementation of the step-by-step execution of microinstructions or stopping at any point in a routine.

The type K587IK2 AU LSIC is a 4-bit universal digital information processing module uniting in its structure mainly elements with the functions of an ALU and internal registers of an SOZU [high-speed memory]. The word length of an MP with an AU LSIC can be increased to 32, i.e., it is possible to unite in a single MP eight AU LSIC's. A chip is placed in a 42-terminal case and contains 2500 transistors. Various combinations of 168 types of microinstructions executed by the AU make it possible to create various and at the same time compatible at the microprogram level instruction sets.

The main purpose of the AU LSIC is to construct the operating units of digital hardware of various word lengths which are multiples of four.

The type K587RP1 UP LSIC is an independent driver of sequences of 14-bit parallel codes and can be used as a microinstruction generator, as well as as a very simple controller. The UP LSIC chip contains about 6000 transistors and is placed in a 42-terminal case. In the MPK the UP LSIC serves as a microprogram control unit based on a programmed logic array (PLM). Information in the PLM is determined by the customer (the user of the MPK) and is firmly entered there in the course of the technological process of the fabrication of the LSIC. The information capacity of the PLM is 64 logical products. Arbitrary programming of the PLM in keeping with the user's requirements determines the diversity of possibilities of using the UP LSIC in the independent mode as a converter and generator of various codes (functions), as a very simple digital control element and the like.

The type K587IK1 OI LSIC is an independent 8-bit digital information processing and switching module serving the purpose of organizing the intra- and extraprocessor parallel exchange of data, of organizing an interface for microprocessors, of constructing interrupt units, and for use in controllers of peripheral equipment for controlling the RAM. The following are the basic operations performed by the OI LSIC: switching of the information signals of three 8-bit channels by means of eight possible methods; arithmetic-logic operations; format conversion operations (from a 16-bit code to an 8-bit and vice-versa, as well as from a serial code into a parallel).

The total number of microinstructions which can be executed by the OI LSIC is 60. The case is a 42-terminal one and the chip unites 3500 transistors. It is possible to expand the word length to 32 by joining four OI LSIC's.

The type K587IK3 AR LSIC is a special-purpose digital independent data processing module. The specialization of the AR LSIC is reflected in its system of 64 microinstructions, oriented toward the rapid execution of the operation of multiplying two operands, which is implemented by hardware, of shifting and of retrieving the bit codes for 8-bit operands.

The basis of the AR LSIC is an array of 8 X 8 single-bit adders by means of which partial sums obtained in multiplying each bit of one multiplier by the bits of another are obtained and shifted. The AR LSIC is controlled by a 7-bit microinstruction. The possibility is provided of increasing the word length to 64 by joining 8 AR LSIC's.

The possible areas of application of computing hardware constructed on the basis of the series K587 MPK are: systems for monitoring and controlling technological processes; systems for program control of machine tools; testing and checking and measuring systems; built-in primary information processing equipment in monitoring and control systems; controllers for controlling peripheral equipment; calculators for very simple engineering and economics calculations; and microprocessor computing systems.

An example of a microcomputer implemented on the basis of the series K587 MPK is the "Elektronika NTs-03" microcomputer, designed for use in systems for controlling technological processes and measuring and checking and testing equipment, for the gathering and preliminary processing of data in information search complexes, for solving computing problems, as well as for use in computing complexes as peripheral processors with special-purpose functions. The "Elektronika NTs-03" microcomputer has the following key characteristics: length of information word--16 bits; rate of execution of operations of the RR type--100,000 operations/s; capacity of memory--32 K; software--cross system for programming on a BESM 6 computer; power requirement--30 W; overall dimensions--480 X 360 X 220 mm; weight--28 kg.

19. Series K589

The series K589 microprocessor set contains seven LSIC's fabricated according to the TTLSh technology and is designed for constructing high-speed MP systems with various kinds of organization and a speed of response on the order of one million operations per second. As does the foregoing one, this set has a microprogram principle of control, modular organization and the ability to expand word lengths of the microprocessor which are multiples of two.

The set includes the following LSIC's: a K589IK01 microprogram control unit (BMU); a K589IK02 central processor element (TsPE); a K589IK03 fast carry circuit (SUP);

a K589IR12 multimode buffer register (MBR); a K589IK14 priority interrupt unit (BPP); a K589AP16 line driver (ShF); and a K589AP26 inverting line driver (ShFI).

The microprocessor per se can be formed in this case by a combination of TsPE, BMU and MBR LSIC's.

The type K589IK01 BMU LSIC is a unit for controlling accessing of a sequence of 9-bit microinstructions from a microprogram memory according to an 8-bit address contained in the instruction word. The difference between the BMU LSIC and the UP LSIC of the K587 series consists in the fact that the first LSIC does not contain microprogram information in itself, but only organizes their readout from the microprogram storage according to assigned rules for the correspondence to each instruction of a sequence of microinstructions, whereas the UP LSIC generates these sequences. In addition, the BMU in conjunction with a BPP priority interrupt unit makes it possible to organize interrupts. The total number of microinstructions which can be accessed by the BMU is 512. The BMU LSIC case is a 40-terminal one.

The type K589IK02 TsPE LSIC includes in its structure an ALU, SOZU [high-speed memory] registers, and a microinstruction decoder and is designed for performing arithmetic and logic operations on 2-bit operands. The TsPE is controlled by a 7-bit microinstruction and the total number of microinstructions is 40. The TsPE LSIC chip is placed in a case with 28 terminals. For the purpose of constructing a microprocessor with a word length of N , it is necessary to join N/2 TsPE LSIC's.

The type K589IK03 fast carry circuit (SUP) is designed for the simultaneous carry of the information of groups of registers to higher-order bits. This need originates in an MP formed by uniting several TsPE's in performing an operation the word length of whose result is greater than the word length of each of the operands. The accomplishment of carry by the sequential shifting of information in each bit would considerably reduce the speed of execution of operations. One SUP makes it possible to organize a carry operation for eight TsPE's, i.e., serves a 16-bit MP. The SUP is controlled from a carry enabling signal from the BMU. The case of the SUP is a 28-terminal one.

The type K589IR12 MBR LSIC is a universal 8-bit register with outputs having three states (logical 0, logical 1 and the state of high output impedance, equivalent to cutting off of the output) and is designed for organizing the bus line exchange of information between various units. For the purpose of controlling the states of the outputs, the MBR has built-in logic. An interrupt enabling signal is also formed in the MBR. The MBR LSIC can be used in the independent mode for the implementation of many types of interface units such as multiplexers, bidirectional line drivers, input/output channels and the like. A chip is placed in a 24-terminal case.

The type K589IK14 BPP LSIC makes it possible by means of external signals--interrupt enabling signals--to halt execution of the current routine, to store the state of the MP and to proceed to servicing an interrupt. The BPP is interrogated at the end of the execution of each instruction and if it receives an interrupt interrogation the BMU proceeds to process this operation. The number of interrupt levels is eight but can be increased by joining several BPP LSIC's. Just as the MBR, the BPP LSIC chip has a case with 24 terminals.

The K589AP16 and K589AP26 line driver and inverting line driver, respectively, are 4-channel commutators and are designed for increasing the load capacity of an MOS LSIC when connecting it to the system line. The outputs of the ShF and ShFI have three states. Input signals are inverted in the ShFI. The cases of both circuits are 16-terminal.

The software of the series K589 MPK includes a microprogram design system implemented by means of a so-called basic technology machine--a high-capacity external computer. The high speed of response and the ability to create various instruction sets on the basis of an MPK microinstruction set, as well as the ability to vary the structure of the MP system, make possible the diversity of applications of the K589 series. The following are considered the main areas of application of MPK's of this series: high-speed controllers with a control signal output frequency of up to 10 MHz; systems for numerical program control of machine tools; high-output data processing systems; and microprocessor computing systems.

Chapter 4.

General Questions Relating to the Application of Microprocessors

20. Methods of Applying Microprocessors; Classification of Microprocessor Systems

A microprocessor itself in the definition which we use here is still not able to process information as a computer, for example, does. However important a microprocessor is, it is all the same a "building block"--one of several necessary elements comprising the basis of various computing units.

The main method of using a microprocessor is the creation on the basis of it and other LSIC's of the MPK of MP computing systems, by which is meant any computing, control or other system in which the processing of information is performed by one or more MP's (fig 18). This concept of an MP system includes calculators and very simple controllers (short-routine control systems in which the operating routine is fixed in the ROM), micro- and minicomputers and multimicroprocessor systems which functionally imitate the capabilities of medium and large computers.

A structurally complete MP system having its own power supply, interfaces with peripheral units, control console and software combination can be called a micro- or minicomputer depending on its word length, speed of response, size and cost. In addition, a distinctive feature of minicomputers is usually considered the presence of diverse peripheral equipment--information display units, an external storage and special-purpose units. There is no clear boundary dividing computers into classes according to the totality of values of these characteristics. This is associated with the constant tendency toward reducing size and cost while simultaneously increasing the word length and speed of response of computers based on microprocessors.

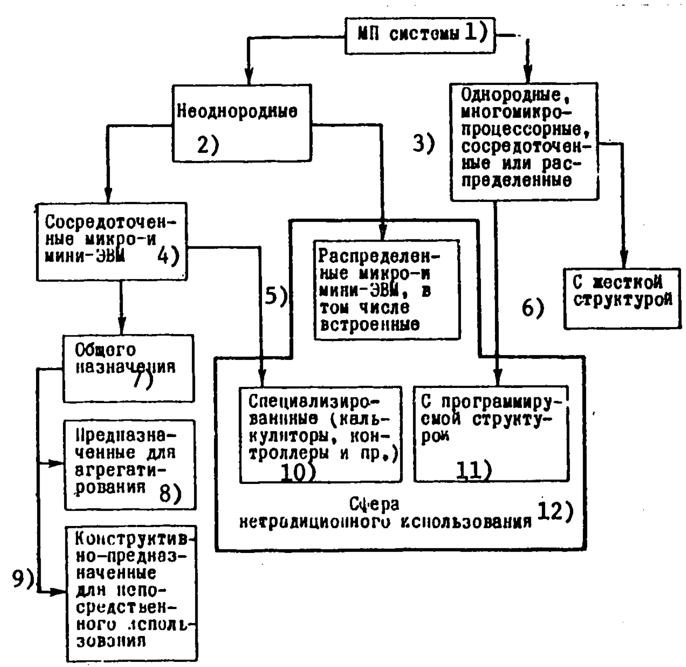

Figure 18. Classification of MP Systems

Key:

1. MP systems
2. Inhomogeneous
3. Homogeneous, multiprocessor, concentrated or distributed
4. Concentrated micro- and minicomputers
5. Distributed micro- and minicomputers including built-in
6. With a fixed structure
7. General-purpose
8. Designed for the building block approach
9. Structurally designed for direct application
10. Special-purpose (calculators, controllers and the like)
11. With a programmable structure
12. Area of untraditional application

For example, during the period 1972-1976 the cost of microcomputers was lowered by an order of magnitude and their speed of response increased threefold. The level of integration of MP LSIC's forming the basis of microcomputers was increased 20-fold during this same period (!), which made it possible for Intel, the leader in the world in the production of microprocessors, to create complicated high-output microcomputer systems and the model 8748, 8048, 8085 and 8086 microprocessors on a single chip [11]. These facts convincingly demonstrate the possibility of creating a functionally complete computing system in a single microcircuit.

It can be said roughly that as of the present a typical microcomputer has a word length of up to 16 bits and a speed of response of up to 200,000 addition operations per second. For minicomputers these characteristics have values of 32 bits and 500,000 to 800,000 addition operations per second, respectively.

In addition, characteristic of microcomputers is the presence of a poorly developed interface for the exchange of information with the outside, the absence of or a small number of peripheral units and a selector mode (spaced over time) of exchange with them. These indicators, respectively, are better in minicomputers.

With regard to degree of specialization or, on the other hand, universality, microcomputers can be divided into "ultrasimple" special-purpose, designed for solving narrow problems (e.g., arithmetic operations in calculators, the simplest control in controllers, substitution of hardware logic by program control of the functions of one and the same microprocessor), and general-purpose. A general-purpose microcomputer must possess a sufficiently universal instruction set and, unlike "ultrasimple," aspire in its development to the perfection of its characteristics, bringing them close in value to those of minicomputers.

General-purpose microcomputers can be structurally readied for the work of an operator, i.e., having a chassis, frame, control console and other required equipment, and can be designed for the building block approach, i.e., for operation in a structurally and functionally unified combination of equipment and therefore not have the components required for independent operation.

Hitherto we have been talking about concentrated computing systems, i.e., about those in which the computing process takes place entirely within the framework of the logical structure of a computer with a microprocessor as the processing and control element. This structure is traditional and practically imitates the functional organization of computers of the premicroprocessor period. The microprocessor made it possible, and this is very important, to realize a fundamentally new approach to organizing computations by creating distributed information processing facilities. Distribution here means primarily the breaking down of the total algorithm for solving a problem into a number of algorithms implemented in parallel and not connected, inasmuch as this is possible, with one another in time and, in addition, the most optimum spatial distribution of the computing process by building special-purpose microprocessor systems directly into source data sensors.

Built-in computing systems are a nontraditional qualitatively new method of applying microprocessors which makes it possible to solve in a new manner problems relating to providing for speed of response, reliability and stability and to reducing the size and weight of equipment for the automatic control, checking and gathering of data. The characteristic features of an MP make possible the built-in control of each individual unit of apparatus or equipment, which makes it possible to create totally automated equipment and processes.

Another nontraditional feature of microprocessors is the substitution of hardware logic, and together with this the designing of the physical structure of a computing system, by programming its structural properties. For example, the functions of various logic elements--a gate, flip-flop, counter, decoder, etc.--can be implemented by the appropriate programming of the same microprocessor with the presence of the required number of storage cells. The functional equivalent of a single logic element, according to estimate data, requires 8 to 16 bits of memory [9]. In the not too distant future the cost of MP LSIC's will be reduced to the extent that the substitution of "hard" logic by programmable structurally identical elements will be economically justified. In individual cases this is taking place already today.

A method of applying microprocessors which deserves attention and is aimed mainly at increasing the speed of response, reliability and adaptability to various classes of problems is the creation of homogeneous multimicroprocessor systems. Unlike the inhomogeneous multiprocessor systems discussed above, homogeneity here means a regular method of uniting a great number of microprocessors of the same type. This in a number of cases makes it possible to increase practically without limitation the speed of response of microprocessor systems by the multiprocessing of computations. In terms of space these systems can obviously be both concentrated and distributed, however both must be constructed according to the principles of the parallel processing of information and of structural homogeneity.

Most promising must be considered multimicroprocessor systems with a programmable structure, uniting the traditional advantages of multiprocessor systems with a nontraditional method of using microprocessors as a logic element with program-controlled functions.

In summing up our discussion of the basic methods of applying microprocessors, we again note the existence of traditional and nontraditional methods of constructing MP systems. The former assumes the creation of microprocessor computing equipment with a fixed logical structure which is spatially centralized, within the framework of which the entire computing process takes place. The second method is characterized by the distribution of computations in space and by multiprocessing in time (inhomogeneous built-in and homogeneous distributed multiprocessor systems), as well as by the substitution of hardware logic by the programming of functional properties.

Both methods open up extensive possibilities for the application of microprocessors in various areas; however it is precisely the nontraditional method which makes it possible to count on the penetration in the not too distant future of microprocessors into all areas of life, making an MP system just as ordinary and irreplaceable a phenomenon as the telephone or toothbrush.

The comparison of general-purpose minicomputers designed with various elements presented in table 9 clearly demonstrates the advantages of traditional MP systems over systems with hard logic.

It is obvious from this table that the product of the speed of response by the power requirement for minicomputers employing series K583 microprocessor LSIC's is twofold lower than in minicomputers using K134 integrated circuits and is fivefold lower than in minicomputers using series K155 integrated circuits.

As demonstrated by an analysis of the effectiveness of using systems employing MP LSIC's as compared with systems employing integrated circuits, the majority of problems not requiring especially high speed of response can be solved successfully on the basis of microprocessor systems designed by traditional methods.

Table 9. Comparison of Characteristics of Different Variants of Minicomputers

Characteristic	Value of parameter for minicomputer variant		
	Variant 1 using series K134 IC's	Variant 2 using series K155 IC's	Variant 3 using series K583 MP LSIC's (YeS [Unified Series] MPK's)
Time for performance of a brief operation, μs	4	1	1
Power requirement, W	6	60	12
Number of IC's	1000	1000	20 LSIC's + 30 IC's

21. General Recommendations on Selecting and Using Microprocessors

Before proceeding to the question of selecting a microprocessor, let us investigate in what cases an MP is generally more effective than hard (nonprogrammable) logic.

In fig 19 an original algorithm is presented for finding the most appropriate element base for a computing system reflecting considerations of the user, who is choosing between integrated circuits and MP LSIC's. It is obvious from this figure that the use of hard logic is justified in two cases--when it is necessary to obtain ultrahigh speed of response in the implementation of complicated algorithms and, on the other hand, in very simple systems with a small number of integrated circuits with a low and medium degree of integration--special-purpose digital automata. If flexibility is required, i.e., a frequent changing of functions by means of software, or the expansion of the range of problems which can be solved is anticipated in the future and the system is fairly complicated, then a microprocessor is used.

Thus, the flexibility of a microprocessor, as well as the distinctive feature of the development of MP systems expressed in the substitution of logical design by programming of the required functions, associated with this flexibility, prove to represent a decisive difference from nonprogrammable logic.

Having decided to use an MP, the developer of a computing system must select the microprocessor most appropriate for his task on the basis of a comparative analysis of the combination of its characteristics and the combination of specified requirements. Of course, influencing this choice, as also the choice of other elements of equipment, is a set of factors which are difficult to take into account which each have a broad range of significance--from the ability to acquire a specific type to the personal liking of the developer. However, without pretending to completeness in explicating this problem, let us dwell on the relationship between certain properties of microprocessors and of systems based on them.

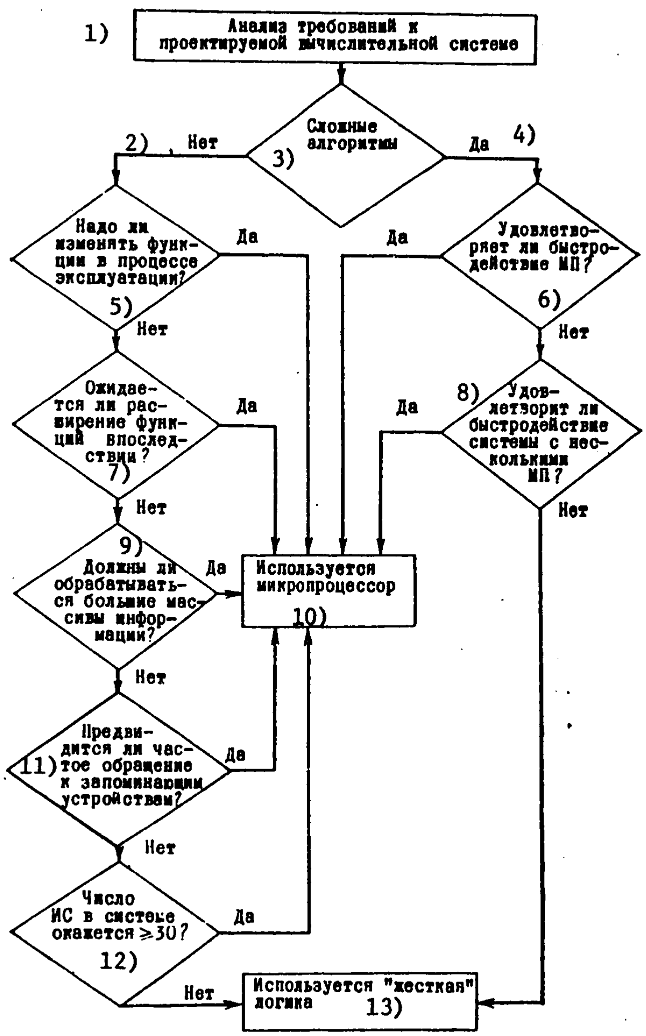

Figure 19. MP LSIC's or IC's?

Key:

1. Analysis of requirements for computing system to be designed
2. No
3. Complicated algorithms
4. Yes
5. Necessary to change functions in process of use?

[Continued on following page]

6. Is speed of response of microprocessor satisfactory?
7. Expansion of functions anticipated later?
8. Will speed of response of a system with several MP's be satisfactory?
9. Are large arrays of information to be processed?
10. Microprocessor used
11. Frequent access to memory envisioned?
12. Will number of IC's in system be equal to or greater than 30?
13. "Hard" logic used

How is a microprocessor to be selected? Partly the answer to this question has already been given in chs 1 and 2 in describing the characteristics of microprocessors and their classification. Here we will indicate how these characteristics are related to such features of microprocessor systems as their architecture, computing capacity, flexibility, complexity of design, overall dimensions, weight and economic efficiency.

By the architecture of an MP system is meant the structure, design and principles of organization of hardware and software, considered not "from within"--from the viewpoint of the developer--but "from without"--from the viewpoint of the user of an MP system.

One and the same characteristic, e.g., the word length of a microprocessor, can belong to the internal structure if it is a question of the internal structure of a microprocessor, or to the architecture if it is a question of the precision which must be guaranteed as the result of using in a system an MP with a specific word length.

Table 10 gives an idea of the relationships between the above-named characteristics of an MP system and the characteristics of a microprocessor.

The minus sign indicates the absence and the plus sign the presence of an influence of the relationship on the characteristics of an MP system, with the double plus indicating a decisive influence. It is obvious from this table that microprogramming, for example, being an important feature of the architecture, determines flexibility and considerably complicates designing, which indicates the need to use special design systems. Intel, for example, produces a system of the MDS800 type, which makes it possible to design completely the hardware and software of MP systems based on multiprocessor sets of the MCS-80 and 3000 types.

The data presented in tables 8 and 10 make it possible to select an MP for a system satisfying specific requirements.

Let it be required to design a simple controller for controlling a technological process according to a single or small number of predetermined algorithms (i.e., relatively inflexible), with low speed of response and with an error of about one percent, without special requirements for utilization factors, overall size, and weight, which replaces 20 to 30 integrated circuits with a low degree of integration.

Table 10. Relationship Between Characteristics of an MP and MP System

MP characteristics	MP system characteristics: Architecture	Computing capacity	Flexibility	Complexity of design	Utilization factors, overall size, weight, economy
Word length	+	++	+	-	+
Number of internal registers	++	++	+	-	-
Presence of stack organization	++	+	-	-	-
Speed of response	+	++	-	-	++
Microprogramming	++	+	++	++	-
Interruption	+	+	++	+	-
Separate data, address and control lines	+	++	+	+	+
Flag	+	+	++	-	-
Electrical features, mechanics	-	-	-	+	++
Presence in MPK of interface and memory circuits	+	-	-	++	-
Cost	-	++	-	++	++

The requirement of simplicity of design according to table 10 assumes, primarily, the absence of microprogramming, which agrees with the lack of a requirement for flexibility, as well as the presence in the MPK of interface and memory circuits. The low speed of response indicates the ability to use one of the MOS microprocessor technologies and the error of one percent requires the use of an 8-bit information word length.

In addition, the MP can have a small number of internal registers and be relatively inexpensive.

According to table 8 these requirements are met by the series K580 MPK (n-MOS, 8 bits, time for execution of an addition operation--2 μs, strict macroprogram control, presence of interface circuits).

A flexible high-speed 16- to 24-bit MP system to replace up to 1000 integrated circuits with a low degree of integration must obviously contain several processor sections with a short word length (two, four or eight) and must employ the bipolar technology (TTLSh, I^2L or ECL) with microprogram control.

In table 8 these requirements are met by a series K589 microprocessor--a microprogrammable 2-bit processor section employing TTLSh circuitry. The unification of eight to 12 of these sections gives the required word length for the system and the time for executing an addition operation, equal to 100 ns, makes it possible to obtain high speed of response. The presence of 10 RON's [general-purpose registers] (more than in a series K580 microprocessor), the possibility of interrupts, and separation of data, address and control lines are conducive to the realization of high computing capacity, flexibility and economy.

The "Elektronika NTs-03" model, built with a series K587 multiprocessor set, can serve as an example of the construction of a 32-bit universal microcomputer with a speed of response of 100,000 operations per second.

A high-speed, economical, long-word-length, flexible and relatively complex MP system for operating over a wide range of utilization factors can be constructed on the basis of the series K583 MPK. The I^2L circuitry according to which it is fabricated ensures the highest speed of response with a low power requirement. Eight-bit processor sections make it possible to increase the word length and microprogramming creates flexibility. However, the relative complexity of designing such a system and its cost will be, as is obvious from table 10, very high.

These examples in no way exhaust the possibilities of the application of series K580, K583, K587 and K589 microprocessor sets; in them are discussed only the most typical cases, helping one to understand what features must be taken into account in selecting a model of a microprocessor for a specific application.

Chapter 5.

Examples of Concrete Implementation of Microprocessor Systems

22. Areas of Application of Microprocessor Systems

As already mentioned more than once, the special properties of microprocessors make it possible to make exceptionally extensive use of systems based on them, and the variety of applications is limited rather by the imagination of developers than by the capabilities of microprocessors themselves. Up to the present time an entire series of trends has been noted in the application of these systems and reports on their further development or extension to new areas of human activity are appearing ever more often.

Already at the present microprocessor systems have been used effectively for the following purposes: for controlling and monitoring production processes in data gathering systems, automated technological lines and machine tools with numerical program control; in systems for processing and displaying information in solving scientific and technical, engineering, economic and other problems, as general-purpose or special-purpose micro- and minicomputers; in communications engineering for accomplishing switching, multiplexing and expansion of the functional capabilities of communications equipment, and in coding equipment; in measuring technology for increasing the accuracy of measurements, automating the measuring process, expanding functional capabilities by the implementation of methods of automatic correction of errors, self-calibration, self-diagnosis and the digital processing of measuring information; in physics experiment equipment for increasing the flexibility and universality of the application of experimental equipment and for automating the research process; for automating the control of transportation traffic and transport vehicles and the operating conditions of engines, for checking observance of road traffic rules and for providing other measures for improving traffic safety; in household appliances and electronic games for automating control and expanding functional capabilities; in commercial and service equipment for the automatic performance of financial operations and in emergency and protection systems; in medical technology in systems for gathering and recording information on the condition of patients and for automation of the investigation and diagnosis of diseases.

This list is not to be regarded as specific for the application of microprocessors. It is simply that the need to use microprocessors came to a head earlier in these areas than in others or other not always objective reasons played a role. Be that as it may, in part following this division which has sufficiently taken form abroad, let us indicate how a microprocessor takes part in information processes taking place in monitoring or control systems.

In the final analysis it is possible to reduce any information conversion system to these two categories. This somewhat unanticipated thesis is not hard to accept if the membership of a system in a specific category is determined by the degree of the participation of man in the information process.

Here we will call a monitoring system a system having an input for a prepared array of data or for information from sensors of the monitored process or entity, and an output whose signals are designed for reception by a human operator. Making decisions in keeping with the information obtained from the system's output, the operator corrects the process, thus closing the feedback loop: entity - monitoring system - man - entity.

A control system is distinguished from a monitoring system by the fact that the decision regarding the need for a specific correction is made by the system itself and the correction (control) signals are also generated in it; therefore, the entity - control system - entity feedback loop is closed without the participation of man in the information process.

Systems which control processes continuous over time with a sufficiently high degree of analog-digital conversion, defined as the ratio between the rate of change of parameters of the controlled entity and the speed of response of the system itself, are said to be operating in real time. This is perhaps the most important and interesting class of systems, the capabilities of which are realized even more effectively with the application of microprocessors.

23. Microprocessors in Systems for Controlling and Monitoring Production Processes

Able to serve as an interesting example of the use of an MP system for monitoring a technological process is the system for sorting lumber, developed at Washington University, which measures the parameters of wood by nondestructive methods and presents complete information on a sample in digital form [12]. The system makes it possible to determine effectively the suitability of wood for a specific method of further processing, taking into account the dimensions, weight and density of the sample. According to the authors' statement, a complete analysis of the properties of a single sample takes less than 2 s, which is especially important for using the system in a production line. The efforts of four people over the course of a month were spent on the development of hardware and software, and special attachments were not required for measuring equipment.

Fig 20 explains the operation of this system.

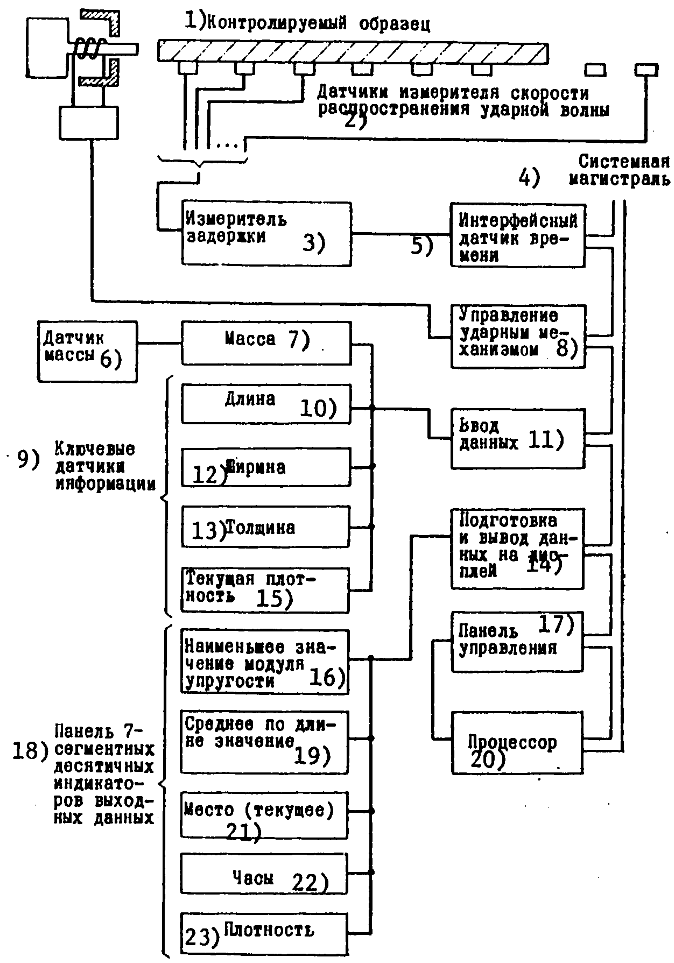

Figure 20. Functional Diagram of Lumber Sorting System

Key:

1. Sample being checked
2. Sensors of shock wave propagation rate meter
3. Delay meter
4. System line
5. Interface timer
6. Weight measuring element
7. Weight
8. Control of shock mechanism
9. Gate-type data transmitters

[Key continued on following page]

10. Length
11. Input of data
12. Width
13. Thickness
14. Preparation and output of data onto display
15. Instantaneous density
16. Lowest value of elastic modulus
17. Control panel
18. Panel of 7-segment decimal output data indicators
19. Length-average value
20. Processor
21. Position (instantaneous)
22. Clock
23. Density

The key factor making it possible to judge the quality of wood is the elastic modulus, uniquely determined by the product of the density by the square of the rate of propagation of a shock wave in the sample. The density is computed by the processor from continuously registered values of the length, width, thickness and weight of the sample, and the shock wave propagation rate from the delay time of its front at fixed distances along the sample. Information is read out onto the display panel on the instantaneous and length-average value of the elastic modulus, the position of the section of the sample with the lowest modulus, the minimum permissible value of the modulus, the density of the sample and the time.

The mechanical part of the system includes a shock mechanism synchronized by pulses generated by the processor, sensors of the shock wave front for measuring the instantaneous value of its propagation time, and sensors of size and weight. The processor section is constructed on the basis of a Motorola model MC6800 microprocessor.

The microprocessor system is entrusted with the following tasks: starting and stopping the time meter at the start and termination of testing of each sample; reading out onto the indicator panel the number of the sample and monitoring values of weight, size, density and elastic modulus; control of the shock mechanism; fixing values of the delay time of the shock wave front and switching off the individual sensor before the start of a new wave in order to avoid a reaction to reflected waves (improvement of noise immunity); receiving data on the length, width, thickness, weight and delay time; computation of density; computation of minimum elastic modulus relative to maximum delay time; computation of averaged value of elastic modulus; finding samples with the lowest elastic modulus (rejection) and determination of the coordinates of the section of the sample with the lowest modulus; and readout of results onto the indicator panel.

Information from analog size and weight sensors is converted by means of analog-digital converters into a digital binary code which is entered through the system line into the microprocessor as input data. The pulses of the time meter also arrive there, whose number is proportional to the delay times of the shock wave front in various sections of the sample.

The processor section of the system can be used without modification for other applications, since at the design stage broader capabilities were given to it than this problem requires. This relates in particular to the memory direct access channel, whose use is not required here, but which makes the system more universal.

The microprocessor system is assembled on three boards--the MP per se, a control board and a memory board, united by the system line (SM).

The MP board includes, in addition to the central processor itself, line amplifiers (MU's) and a small number of logic circuits with a low degree of integration (fig 21).

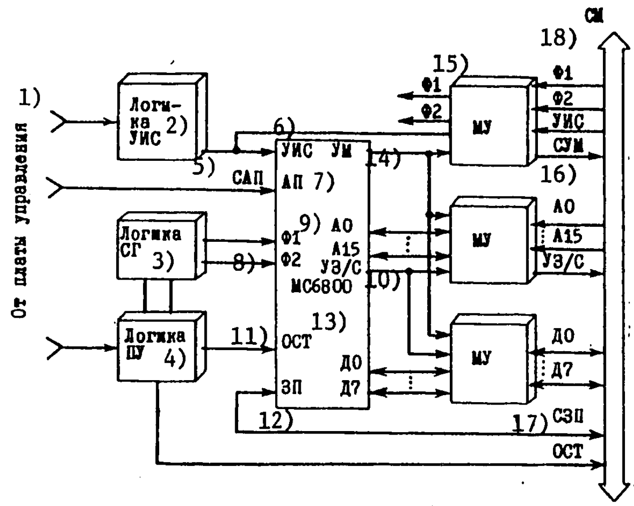

Figure 21. Structure of MP Board

Key:

1. From control board
2. Logic for setting initial state
3. Synchronizing generator logic
4. Step-by-step control logic
5. Power line failure interrupt
6. Setting initial state
7. Power failure
8. Synchronization lines
9. Address lines
10. Write/read control
11. Halt
12. Interrupt enable
13. Data lines
14. Bus line control
15. Line amplifiers
16. Bus line control signal
17. Interrupt enabling signal
18. System line

The board communicates with the system line by means of address lines (A0 to A15), data lines (D0 to D7) and control lines. The latter includes a line for setting the initial state (UIS), an interrupt enabling line (SZP), a halt line (OST), synchronization lines (F1 and F2) and an address write/read control line (UZ/S). In addition, the MP board is connected directly to a board for controlling UIS lines, interruption upon failure of the power line (SAP), bus line control (UM) and step-by-step control (PU).

The signal for setting the initial state is generated at the moment the power is turned on and retrieves from the ROM a special routine which sets to zero all counters and registers of the MP. The same signal can be sent from the control panel at any moment of the execution of the routine. After setting the initial state, the first instruction initiating the operating routine is automatically accessed from the ROM.

Interrupts can be carried out in two cases--after response to an interrupt enabling signal periodically generated by the control board, and also with impermissible deviation of the value of the supply voltage from the nominal.

In the first method an interrupt enabling signal (SZP) is used and in the second a power line failure signal (SAP).

The synchronizing generator with driving logic, located on the microprocessor board, generates two phases of pulses with a clock rate of 500 kHz, which determine the dynamics of the operation of the entire processor section. The clock rate for the MC6800 microprocessor can be increased to 1 MHz (cf. table 8), but in this case this does not result in a noticeable increase in speed of response of the system as a whole, since here it is determined by the mechanical section.

The halt input makes it possible to stop the execution of the operating routine by means of a signal from the control panel, as well as to implement its step-by-step execution, which is especially important in debugging and finding errors in a newly entered routine.

All output signals of the MP enter the system line via a line amplifier making it possible to increase the load capacity, which in the MC6800 MP corresponds to a total of one input of an ordinary TTL integrated circuit.

Commutation of all lines of the microprocessor with the system line, with the exception of lines F1, F2 and UIS, is accomplished by means of the SUM signal generated in the microprocessor. A write/read control signal is also generated in the microprocessor and serves the purpose of implementing the natural sequence of these operations in the execution of an instruction.

The control board, just as the microprocessor board, is designed as a universal element of the structure, permitting various applications without any kind of modification.

It contains an address decoder (DA), a data register (RD), a register for signals from the control panel (RP), interrupt servicing logic (LP) and generators of signals for the control panel (GP), for controlling states of the processor (GU), for halting and step-by-step control (GO and PU), and emergency interrupt (AP) (fig 22).

The address decoder (DA) converts the 16-bit binary address code into signals directly controlling the operation of the entire processor section with data presented to this address.

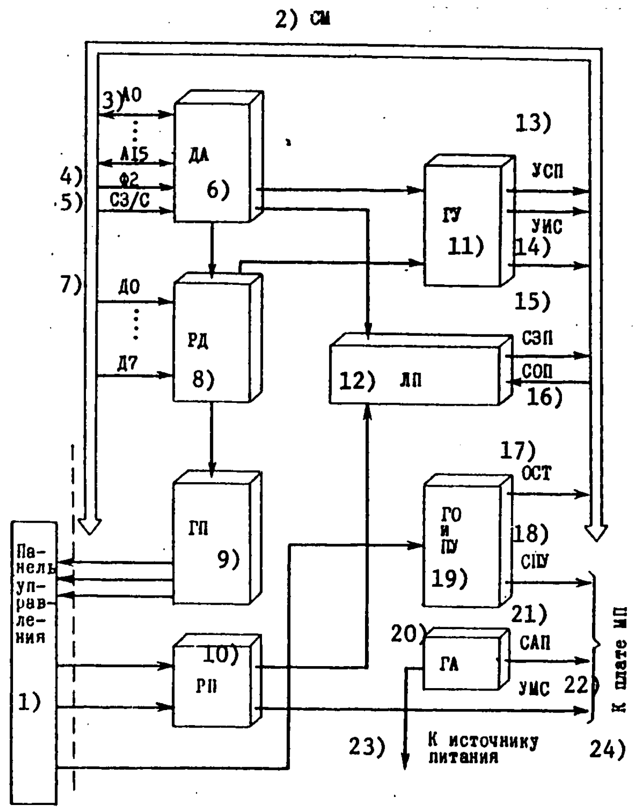

Figure 22. Structure of Control Board

Key:

1. Control panel
2. System bus line
3. Address lines
4. Driving lines
5. Write/read signal
6. Address decoder (DA)
7. Data lines
8. Data register (RD)
9. Control panel signal generator (GP)
10. Control panel signal register (RP)
11. Processor state control signal generator (GU)
12. Interrupt servicing logic (LP)
13. Processor state control signal (USP)
14. Initial state setting signal (UIS)
15. Interrupt enabling signal (SZP)
16. Response signal (SOP)
17. Halt (OST)
18. Step-by-step control signal (SPU)
19. Halt signal generator and step-by-step control signal generator (GO and PU)
20. Emergency interrupt signal generator (GA)
21. Emergency interrupt signal (SAP)
22. Microprocessor system control signal (UMS)
23. To power supply
24. To MP board

Control signals are generated by generators GU, GP, GA, GO and PU. An interrupt is organized by the generation of an interrupt enabling signal (ZP), which periodically interrogates all units requiring it and in the case of a response (an SOP signal) halts the process for the output or entry of information through the system line (SM). The signal for controlling the state of the processor (USP) determines the state of the processor during the course of each cycle, as well as its beginning and end.

In the step-by-step execution of a routine, set from the control panel, the contents of the data register (RD) are indicated on the panel by means of signals generated by the GP generator.

The halt and step-by-step control signal generator (GO and PU) generates the appropriate signals upon an instruction from the control panel.

An interrupt ensuing as the result of a power failure and made possible by the AP generator is distinguished from a stop by the fact that after setting of the required value of the supply voltage the system is automatically set to the initial state and continues functioning from the first instruction of the operating routine. After a stop, as also after an interrupt, for the purpose of exchanging information with a peripheral unit the routine continues to be executed from the step at which it was interrupted.

SPU, SAP and UIS signals enter the microprocessor board by bypassing the SM line, and all other signals of the control board are transmitted through it.

The processor's memory is also located on an individual board and permits both an arbitrary increase in its volume and alteration of its structure. In this case the total memory capacity is 32 Kbits, 2048 bytes or 8-bit words (16 Kbits) of which are diverted for storage of the operating routine. In the process of the execution of a routine this information can only be read, and in a single sequence determined by the routine itself. The remaining 16 Kbits form the RAM, i.e., can be read and written arbitrarily, whereby 1 Kbit serves the purpose of on-line storage of information from the input/output of peripheral units.

An example of the unification of the three boards of this processor with two peripheral units is given in fig 23. All inputs/outputs of the boards are united by a parallel line, with the exception of the SOP signal lead, which passes through the peripheral units sequentially, which determines the time priority of the interrupts performed through it. This example differs from the processor section of the lumber sorting system described only by a lower number of peripheral units connected to the system line.

In the lumber sorting system an interrupt can be caused for three reasons. The first reason is checking of the correctness of functioning of the system by the operator by means of switches on the control panel. The second is a start signal initiated from the control panel and the third is a signal for termination of measurement of the shock wave propagation rate and the start of the processing of data obtained as the result of measuring.

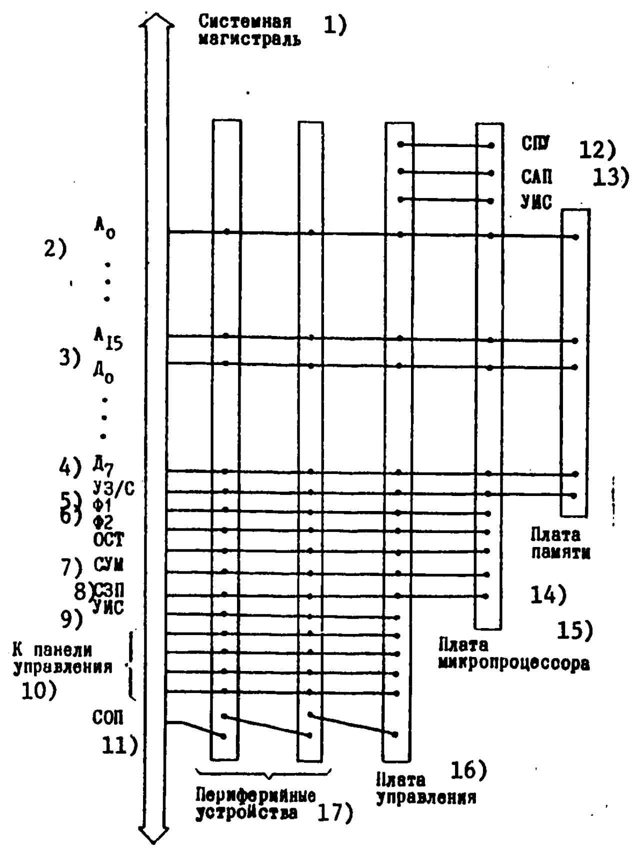

Figure 23. Variant of Unification Into a System of a Processor, Memory and Two Peripheral Units

Key:

1. System line
2. Address lines
3. Data lines
4. Write/read control
5. Synchronization lines
6. Halt
7. Line control signal
8. Interrupt enabling signal
9. Initial state setting
10. To control panel
11. Interrogation response signal
12. Step-by-step control signal
13. Emergency interrupt signal
14. Memory board
15. Microprocessor board
16. Control board
17. Peripheral units

The monitoring system described serves as an example of the simplest utilization of a microprocessor from the viewpoint of the algorithm executed by it and the speed of response thereby required. Much more widespread in practice is the problem of controlling production techological processes in real time, which is solved at the present time by analog and digital automation equipment based on centralized computing systems of relatively high capacity.

Preferred for this kind of control has been and remains the proportional-plus-integral-plus-derivative control (PID) method, whose essence is illustrated by fig 24. The method consists in introducing multiloop feedback, the main loop of which accomplishes only integral (I) regulation and encompasses the proportional (P) and derivative (D) regulation loops [13].

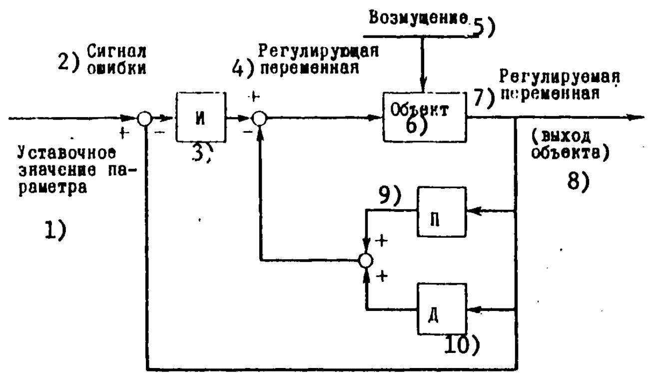

Figure 24. Functional Diagram of Controller Implementing the Method of Proportional-Plus-Integral-Plus-Derivative (PID) Control

Key:

1.	Control value of parameter	6.	Entity
2.	Error signal	7.	Controlled variable
3.	I	8.	(Entity output)
4.	Controlling variable	9.	P
5.	Perturbation	10.	D

The error signal is generated as the result of the comparison of the output signal (controlled variable) with some parameter assigned outside (control value). The value itself of the controlling variable depends on the magnitude and time of the effect (i.e., the result of integration) of the error signal, as well as on the rate of variation and instantaneous value, i.e., the result of differentiation and linear transformation, of the output signal.

The PID method of control has already for almost a half century been the main one in systems for the automatic control of production processes and with proper use it gives very good results. With the transition from analog controllers to digital controllers, routines simulating analog laws of control were written for digital controllers. Thus, a digital PID control algorithm originated which possesses greater flexibility than the analog.

A digital computer for controlling a technological process was installed for the first time at a chemical plant in the USA in 1959. Accomplishing centralized digital control, it occupied the upper rung in the hierarchy of the control system and assigned control values to distributed analog controllers.

Control minicomputers, and after them microprocessor systems, initiated the next stage in the development of equipment for the automatic control of processes. The changeover from centralized computers to distributed made it possible to solve control problems on a qualitatively new basis, including with the employment of the PID method.

Distributed control was the only method used before the appearance of computers; however, the microprocessor variant of distributed control has considerable differences which determine its advantages both over the analog and over the centralized digital method. This difference consists primarily in the use of a data line, i.e., a single- or multiwire line connecting all "controlled process (OU) - control processor (UP)" circuits with the central processor (TsP), which organizes the operation of the entire system and reads out operating information on its operation onto displays (fig 25a and b).

It is believed that complexes of this sort combine the reliability of analog systems with the universality, diversity of algorithms and centralized storage of information which is characteristic of digital systems.

An important feature of distributed control systems is their high stability, which means that the failure of each independent low-level control circuit does not result in loss of working capacity of the entire system, i.e., has less serious consequences than failure of the processor in a centralized system.

The following are considered the main problems which must be solved in designing and introducing distributed systems for controlling production processes:

The ensurance of high reliability in the transmission of digital data through lines of considerable length (on the order of dozens and hundreds of meters) under conditions of the intense influence of industrial electromagnetic interference.

Improving the noise immunity of digital buffer units operating on the bus line.

The creation of a special interface for the exchange of information between peripheral control circuits and the central processor.

At the present time several foreign firms produce MP systems for the distributed control of production. For example, Honeywell (USA) offers users a system able to control 128 circuits for each of several remote terminal units, whose number can be increased. Thirty-two circuits are controlled by a single remote terminal in the MP system of the Yokogawa firm (Japan). Both systems use coaxial cables for transferring data.

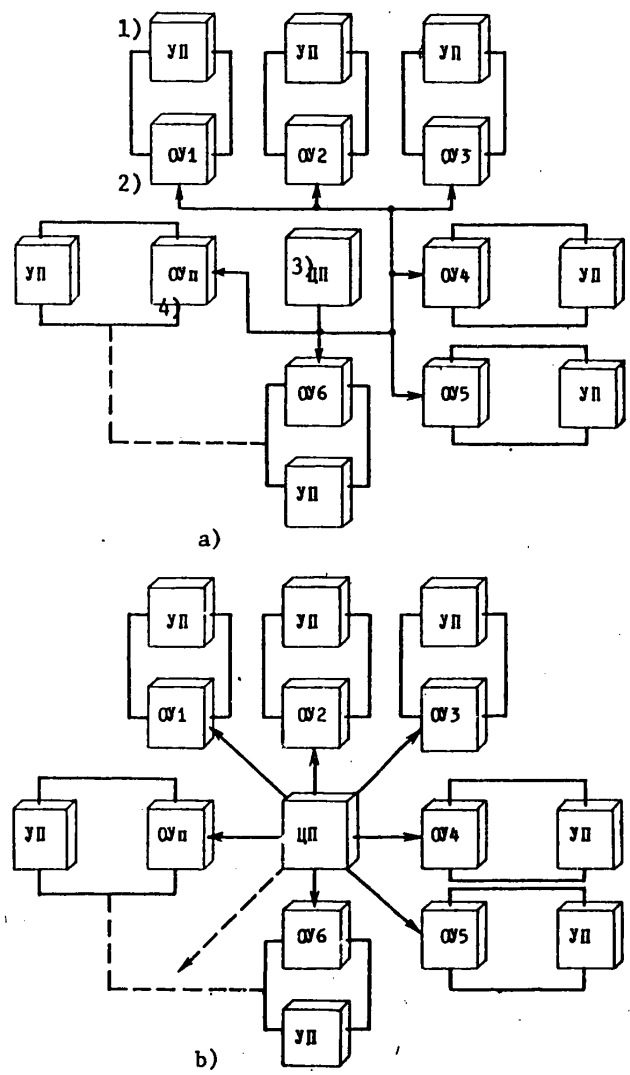

Figure 25. Bus Line Method of Uniting "Controlled Process (OU) - Control Processor (UP)" Circuits into a Control System with a Branched Bus (a) and the Independent Connection of "OU - UP" Circuits (b)

Key:

1. Control processor (UP)
2. OU1 [controlled process No 1]
3. TsP [central processor]
4. OUp [added controlled process]

With the introduction of MP systems characterized by small size and low cost, the number of production processes the digital control of which is economically justified has been increased. This increase is due to the ability to control at low levels right down to individual technological operations. For example, in addition to Honeywell and Yokogawa, who supply their remote terminals individually as small built-in multicircuit systems, Bristol (USA) produces a control system employing a microprocessor having eight circuits, and Measurex a system controlling six circuits. These MP systems are examples of small low-level independent systems for controlling production processes.

24. Microprocessor Systems for Expanding the Functions and Improving the Key Characteristics of Communications Equipment

Communications equipment has been and remains the most important entity for the application of digital computer technology, and the use of microprocessors in communications equipment has opened up new prospects here. As early as 1976 according to the data of the journal ELECTRONICS EQUIPMENT NEWS 16 percent (in terms of cost) of all microprocessors produced in the world were used for communications needs. This figure is shown to be especially significant if it is taken into account that during this year 15 percent of microprocessors found an application in industrial technology, 10 percent in measuring equipment and 4 percent in transportation [14].

Telephony was one of the first areas of application of microprocessors. As early as 1974 Chester Corporation created the BCS-50 individual automatic telephone exchange designed on the basis of a model 8008 microprocessor [15]. The microprocessor here serves the multiplex mode of operation, distributing information over time intervals (regarding multiplexing cf. sec 1), and also controls the connection, disconnection and other states of user stations. Special features or restrictions for each user are stored in the ROM. The same firm later developed an auxiliary MP system designed for operating together with the BCS-50, called the SMDAS. It is based on a model MC6800 microprocessor. The SMDAS serves the purpose of making connections and maintaining communications according to any predetermined time schedule.

In 1977 a report was published on the creation of an independent radio telephone system, the model GL2000, joined to the telephone network of the USA and Canada [16]. This system employs an IM6100 microprocessor and accomplishes the following: scanning and the establishment of communications through any free channel of a subscriber's telephone network; automatic two-tone ringing; reference dialing (makes it possible by pressing one or 10 buttons to call any of 10 subscribers with 10-digit numbers programmed in advance); repeated calling of a busy number; and indication of the current time and connection at a given moment of time.

The terminal is of small size and weight and can be installed in an automobile, for example.

In the not too distant future the use of MP's in telephone systems will obviously make it possible to solve the problem of converting audio signals into digital code and vice-versa for the purpose of transmitting only digital information through communications lines.

Generally speaking, the use of microprocessors will make it possible to expect of the telephone of the future the implementation of such features as: button dialing with conversion of the signal into disk dialing pulses; the transmission of tone-type call signals with control of their amplitude and frequency; the representation on a digital indicator of the time of day, the length of a connection, the number dialed, the last number dialed, a number to be transmitted repeatedly from the memory of the automatic dialing unit and the number of any subscriber taking part in a connection; internal holding of a line with an indication of its retention; automatic dialing according to numbers stored in the memory with the possibility of their re-entry; repeated dialing of the last number dialed by pressing a "Repeat Call" button; programming of numbers for urgent connections by pressing a single button; indication of functions performed at a given moment; connection to internal communications lines; employment of a communications unit with a system for transmitting data and music through a line in the hold state [17].

In addition to telephone communications, the use of microprocessors has opened up broad prospects in radio communications equipment. Able to serve as an example is a report on the use of an MC6800 microprocessor in two stationary 100- and 400-W radio stations serving the purpose of establishing two-way communications for a great number of radio sets of the backpack type, served by operators at forward positions with a command station which can be at a considerable distance both from the positions themselves and from a stationary radio station serving the purpose of a radio relay unit [18].

Automatic tuning to a fixed frequency in steps of 100 Hz in 1.5 s is accomplished by means of a microprocessor in the 2 to 30 MHz band. In addition, the microprocessor controls the operation of a high-speed vacuum relay switch which alters the reactance of the high-frequency section, at the same time compensating the variation in the impedance of the antenna at various operating frequencies and totally automating adjustment of the antenna.

The high performance of the relay transmitter, obtained on account of using a built-in MP system in it, has made it possible to reduce considerably the weight and size of backpack transceivers. With a transmitter power of 10 W a set of this sort weighs 7 kg and is about 3 dm^3 in size.

25. Microprocessor Systems for Improving the Accuracy of and for Automating Measurements

The use of microprocessors in measuring instruments makes it possible to achieve a whole number of positive results which cannot be achieved by other means. The most characteristic requirements for measuring equipment are the requirements for accuracy and for preserving it for an extended period over a wide range of the influence of destabilizing factors. For the purpose of compensating time and use instability causing a change in the function for the conversion of a measured value into that observed, it is almost always necessary to calibrate instruments directly before measurement or at certain intervals representing test intervals. This as a rule is a relatively labor intensive operation and is often insufficiently effective since the parameters of an instrument can change rather quickly during the time of a measurement. For the purpose of reducing the error caused by these changes it is recommended that the measuring instrument be prewarmed or that it be kept in the switched-on state before beginning measurement, which, of course, reduces the capacity for on-line use or simply makes the instrument inconvenient to handle.

One important function entrusted to a microprocessor used as part of measuring equipment is therefore the function of automatic self-calibration, carried out not only before measuring, but also in the process of the effect of the signal of the measured quantity on the input of the meter. The frequency of this calibration can be fairly great for the purpose of carrying out a great number of calibrations during the period of a single measurement.

Another important capability afforded by the use of a microprocessor in a measuring instrument is the possibility of preprocessing of the output information of the meter itself for the purpose of expanding the functional capabilities and improving the characteristics of the measuring instrument as a whole. As the result of this processing it is possible to average automatically the results of measuring, to reduce quantities to a specific dimensionality, to select the optimum measuring range, to compute assigned functions, and the like, in other words, to obtain from the measurement precisely the information which is required in each specific case.

And finally the third important advantage realized by using a microprocessor is the possibility of a self-check and diagnosis of the measuring instrument, i.e., the detection and indication of the location of a discovered malfunction, and, if this is possible, the elimination of it by the connection of standby equipment or the selection of the proper operating mode. This property is especially important for independent measuring systems with high reliability, such as, for example, systems for testing and diagnosing spacecraft.

Of no small importance also is the reduction in the size, weight and power consumption of measuring equipment in which the above-listed properties are realized by using a microprocessor.

One of the first digital measuring instruments realizing the advantages of using a microprocessor is the Systron Donner (USA) 5.5-bit model 7115 multimeter with a built-in model 4004 microprocessor [19].

It measures d.c. voltage, the effective value of alternating current, resistance and ratios of these quantities. The multiprocessor accomplishes programmed coupling of the real conversion function of the meter with constants stored in its memory, i.e., automatic self-calibration, as well as the statistical averaging of readings, linearization of measured quantities and the preprocessing of measurement results according to a specific program.

These functions have made it possible to increase approximately fivefold the accuracy of the instrument: Its error is 0.002 percent of the value of the measured quantity and 0.001 percent of the measurement limit, whereas the error of the majority of 5.5-bit multimeters without a microprocessor is not less than 0.01 percent of the value of the measured quantity.

The increase in accuracy is achieved on account of eliminating the influence on measurement results of the ambient temperature, the "aging" of elements (before the automatic zero setting the instrument measures the drift, stores it and then subtracts it from the value of the measured quantity), as well as of random spikes of the measured quantity (by averaging a sufficently great number of measurements).

To a no smaller extent the accuracy of the instrument is increased on account of reducing errors associated with instability of the internal reference voltage source (standard). In the process of self-calibration the instrument compares the instantaneous value of the voltage of the reference source with its digital equivalent stored in the memory in the form of a corresponding digital code. The result of the comparison is stored and is used for corresponding correction of the measured value of the input quantity.

Essentially in this instrument the standard is the digital code, in relation to which in each measuring cycle the reference voltage source is checked, performing essentially the function of a second standard. Errors associated with instability of the standard are totally eliminated in this case and the accuracy of this check is determined exclusively by the word length of the digital code and the error of digital-analog or analog-digital (as a function of comparison in analog or digital form) conversion.

Able to serve as another interesting example of the application of a microprocessor in measuring equipment is the Hewlitt Packard (USA) model 1722A oscillograph [20]. The so-called double-trace delayed presentation method is used in it for the purpose of measuring time intervals. The advantage of this method is extreme measurement precision, as well as the additional functional capability of the convenient, fast and accurate measurement of typical parameters of pulsed signals--rise and fall time, duration of a pulse at a given level and the like. However, this method is distinguished by complexity and only the use of a built-in controller based on a type 8008 microprocessor made it possible to implement it.

For the purpose of measuring it is sufficient for the operator to match an additionally illuminated display section with the necessary signal pattern section. The result of measuring duration, frequency or the signal, selected by pressing the appropriate button, lights up automatically on a digital display. The microprocessor makes it possible to set the measuring range, to compute duration and frequency and also to convert and read information out onto the display. The time interval measuring error of 0.7 percent is the lowest achieved in visual registration.

26. Microprocessor Systems in Household Appliances and Electronic Games

Mass consumption goods potentially represent the most popular area of application of MP systems. The high reliability and steadily declining cost of microprocessors are factors deciding in their favor the question of the choice of element and technological base for systems for automating the control of home appliances to replace analog, discrete digital, electromechanical and other kinds of equipment. No less attractive is the ability to gain new functions in home appliances along with traditional ones with an insignificant increase in cost, which has also determined the advantages of microprocessor systems over any others.

Any enumeration of mass consumption goods containing microprocessors will be incomplete and inadequate, since reports of new developments in this area are being published constantly. Having first appeared in pocket calculators and electronic timepieces with added functions, microprocessors have been swiftly gaining ground in mass consumption goods, increasing their diversity in the process. Today microprocessors have been firmly established in refrigerators and microwave ovens, in sewing and washing machines, in air conditioners and heating systems, in television and electronic games, and even in coffee makers the need for and possibility of effectively using a microprocessor has been established.

Universal microprocessors produced in large quantities for a wide range of applications are often used for these purposes, but it must be mentioned that no less often it proves to be economically advantageous to develop special-purpose LSIC's, since their manufacturing volume can also be fairly great, and precisely this condition has been and remains decisive for ensuring the economy of microelectronic products.

First-priority taking into account of the economic factor and the problem associated with it of selecting between standard microprocessors and those fabricated on a special-order basis represent perhaps the main feature of the development of microprocessor systems for mass consumption products.

An example of the effective replacement of electromechanical control by digital is the high-quality Accutrak 4000 record changer with wireless remote control [21]. It has a built-in microcomputer making it possible to play records in any sequence according to a program entered in advance by means of a keyboard, to change records, and to turn the changer on and off. The cost of a unit with these capabilities implemented by other methods would have been prohibitive.

Able to be considered another example of this kind is the use of a microprocessor for controlling the operating cycle of a washing machine [2]. A program specified before washing by means of several keys contains information on the required water temperature and washing time and particularities. The microprocessor interrogates a temperature sensor and according to its value controls a built-in heater, and also determines the instant for switching the motor on and off. At the end of washing, the dirty water is drained and the motor is turned on for the squeeze-dry cycle. If the program calls for washing woolens, the squeeze-dry cycle is omitted. In addition, the microprocessor cuts off the power in case of the origin of an electric shock hazard. A simplified flowchart of the algorithm for functioning of the MP system is presented in fig 26.

The application of microprocessors has served as a factor providing an incentive for the appearance of a great number of various electronic games characterized primarily by a high degree of "intellectuality." The most widespread have become games designed as attachments to a television set, which are connected to its antenna input. The television screen acts as the playing field, on which an image of moving and stationary objects is formed, which are controlled by the players from special entry consoles. The conditions of the game and the configuration of objects on the screen can be specified by means of replaceable modules based on ROM's.

Thus, use of these games has taken on the character of the use of a record playing system--the basic system is purchased at a relatively high price but playing capabilities are expanded by the acquisition of inexpensive replaceable modules.

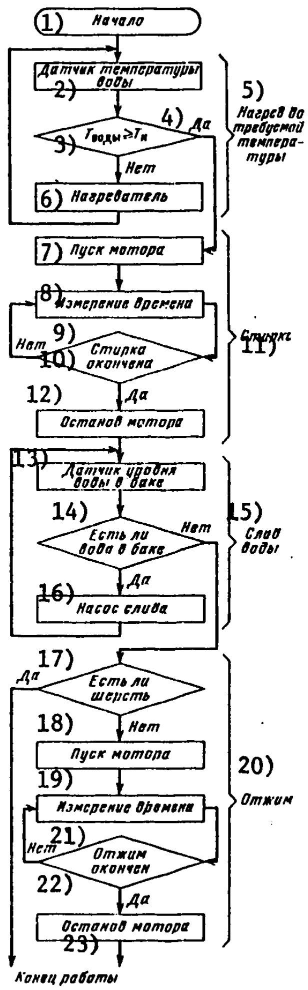

Figure 26. Flowchart of Algorithm for Functioning of MP System for Controlling a Washing Machine

Key:

1.	Start	6.	Heater
2.	Water temperature sensor	7.	Start motor
3.	$T_{water} \geq T_{nominal}$	8.	Measure time
4.	Yes	9.	No
5.	Heating to required temperature	10.	Wash complete
		11.	Washing

[Key continued on following page]

12. Stop motor
13. Sensor of water level in drum
14. Is there water in drum?
15. Drain water
16. Drain pump
17. Are there woolens?
18. Start Motor
19. Measure time
20. Squeeze-dry cycle
21. Is squeeze dry finished?
22. Stop motor
23. End of operation

For example, the first programmable game system, the Fairchild VES, which has been manufactured since 1976, is organized in this manner [21]. The basic unit contains two games--"Tennis" and "Hockey"--and in addition replacement modules can be added for quite different games--from "Tic-Tac-Toe" to "Star Wars." The Fairchild F-8 microprocessor is the basis of the game system. Control of the moving objects on the screen is accomplished in this system by means of two remote units furnished with control knobs.

The RCA Studio II game system, unlike the above, is controlled from keyboard consoles and has more developed "intellectual" capabilities. The keys are used for setting conditions and for the game itself. A cable connecting the system to the antenna input of a television set serves at the same time for delivering supply voltage to the unit.

The system makes it possible by means of a keyboard to select programs for five different games. One program makes it possible to draw on the television screen any kind of picture and to erase and correct drawings. A second program simulates automobile races, creating dangerous situations which must be avoided, whereby the moment of the occurrence and the nature of the danger are not foreseeable in advance. A third program sets up a bowling alley and two others games for speed of reaction and the development of skills in calculating and handling a graphic information input unit.

The structure of games can be altered by replacing special cassettes which are sold widely. The game system is constructed on the basis of an RCA COSMAC microprocessor and contains in addition to it a total of four LSIC's.

In addition to the creation of programmable television games, the use of microprocessors has made it possible to expand the capabilities of non-television active games. Able to be placed under this heading, for example, is the Fidelity chess trainer, utilizing an NIC (Japan) 8080A microprocessor and substituting for a partner of average skill [22]. The game system is combined with a chessboard. A move is entered into the system by means of a keyboard console, to which the system reacts by displaying the counter move on a digital display.

In concluding this description of the specific applications of MP systems it is necessary to stress again how important a role for popular introduction is played by their cost, which is reduced in proportion to the mastery of microprocessors in large-lot production. Actually the use of microprocessor systems becomes feasible almost everywhere where their cost proves to be approximately an order of magnitude lower than the cost of the product itself, which does provide grounds for hoping for the general use of microprocessors in the not too distant future.

Bibliography

1. Merrit Rich. "Microprocessor User Survey Results," INSTRUMENTATION TECHNOLOGY, Vol 23, No 4, 1976, pp 34-40.

2. Blomeyer-Bartenstein, H.P. "Microprocessors Key of the Equipment Generation Tomorrow," COMPONENTS REPORT, Vol 11, No 2, 1976, pp 33-36.

3. Grinkevich, V.A. "Principles of the Structural Organization of a Unified Element Base and Data Processing Facilities Based on LSIC's," PRIBORY I SISTEMY UPRAVLENIYA, No 6, 1978, pp 3-7.

4. Khilburn, Dzh. and Dzhulich, P. "Mikro-EVM i mikroprotsessory" [Microcomputers and Microprocessors], translated from English, edited by S.D. Pashkeyev, Moscow, Mir, 1979.

5. Fullagar, D. "Getting Microprocessors into Perspective," ELECTRONIC ENGINEERING, Vol 48, No 580, 1976, pp 61-63.

6. "Micropocesadores y microcomputadores," 1976, Barcelona.

7. Glazov, G.Ya., Drizovskiy, L.M. and Korennov, Ye.F. "Know-How Gained in Development and Application of Microprocessors, a Review," PRIBORY I SISTEMY UPRAVLENIYA, No 8, 1977, pp 18-21 and No 9, pp 15-18.

8. Harruson, P. "The Impact of the Microprocessor," DATA PROCESSING, Vol 17, No 3, 1975, pp 214-216.

9. Prangishvili, I.V. "State of the Art and Development Trends of Microprocessors and Microcomputers," IZMERENIYE, KONTROL', AVTOMATIZATSIYA, No 1 (9), 2 (10), 1977.

10. Khvostantsev, M.A. "Microprocessors and Data Processing Systems, a Review," ZARUBEZHNAYA RADIOELEKTRONIKA, No 9, 1975, pp 31-60.

11. Kornstein, H. "Third-Generation Microcomputers," MICROELECTRONICS AND RELIABILITY, Vol 16, No 4, 1977.

12. Logan, J. and Kreager, P. "Using a Microprocessor: a Real-Life Application," COMPUTER DESIGN, Vol 14, No 9, 1975, pp 69-77.

13. Auslender, D.M., Takakhasi, Ya. and Tomidzuka, M. "Use of Microprocessors for Direct Control of Processes and Algorithms for Controllers Utilizing Microprocessors," TIIER, Vol 66, No 2, 1978, pp 113-124.

14. Banks, M. "MPU's--a Present and a Future," ELECTRONIC EQUIPMENT NEWS, No 12, 1976, pp 20-21.

15. Kaye, David N. "Microprocessors Help to Communicate by Voice and Bit Stream," ELECTRONIC DESIGN, No 8, 1976, pp 58-61.

16. John, R. "Francis Microprocessor Boosts Radiotelephone Service," COMMUNICATION NEWS, August 1977.

17. Melvin, D.K. "Use of Microcomputers in Telephony," TIIER, Vol 66, No 2, 1978, pp 91-103.

18. "Microprocessors in the Latest Military Communications Equipment," ELEKTRONIKA, No 22, 1977, p 15.

19. "Digital Voltmeter with Microprocessor," ELEKTRONIKA, No 14, 1977, p 17.

20. "First Oscillograph with Microprocessor," ELEKTRONIKA, No 2, 1975, p 85.

21. Russo, P.M. "Microprocessors in Mass Consumption Goods," TIIER, Vol 66, No 2, 1978, pp 25-37.

22. "Chess Sparring Partner," ELEKTRONIKA, No 5, 1976, p 11.

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APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000400070010-9